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Avoiding Bus Bunching: From Theory to Practice

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Joint work with: Juan Carlos Muñoz and Felipe Delgado

Outline

- The bus bunching problem
- Proposed control strategy
- Simulation results
- Pilot test results and Implementation Challenges
- Conclusions

Motivation: Efficiency in the use of road space

BUS RAPID TRANSIT
ACROSS LATITUDES AND CULTURES

What can we say about the user?

- Perceives waiting time and walking time twice as important as travel time inside the vehicle.
- Avoids transferring, specially if they are uncomfortable
- Needs a reliable experience
- Requests a minimum comfort experience
- Requests information
- Needs to feel safe and secure

What can we say about bus service?

Bus is critical to provide a good door-to-door transit alternative for many journeys:

- Much higher network density and coverage than rail
- Greater flexibility in network structure
- Low marginal cost for service expansion

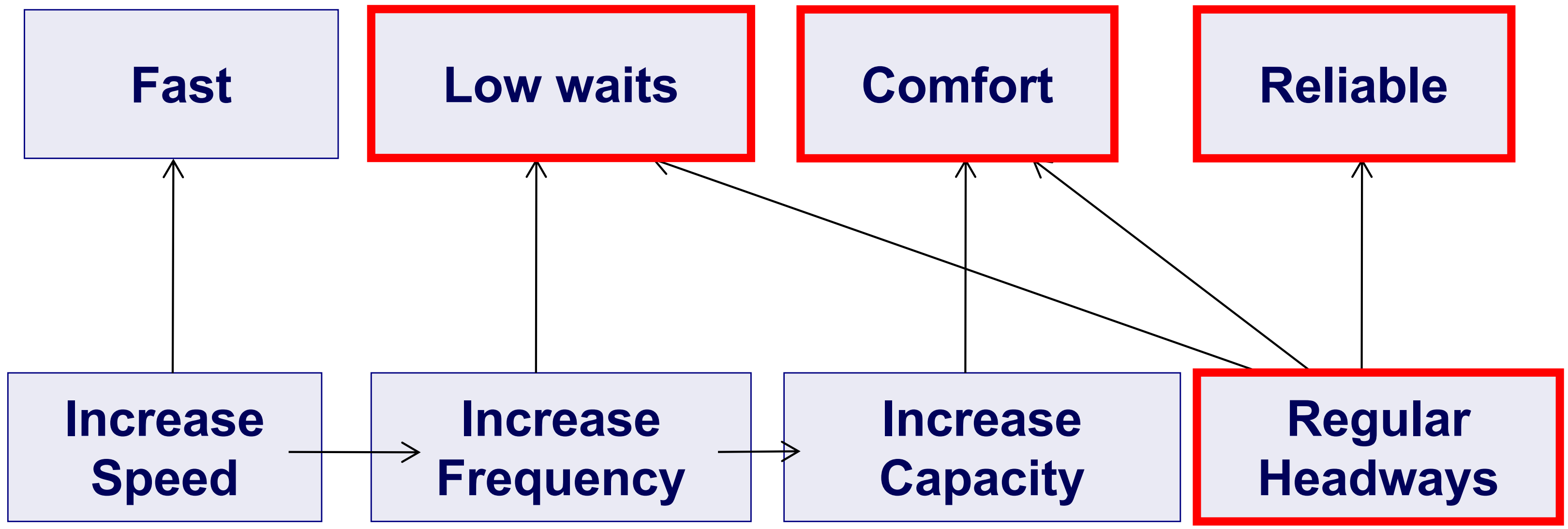
BUT as traditionally operated, it also has serious limitations:

- Low-speed
- Subject to traffic congestion
- Unreliable
- Harder to convey network to the public
- Negative public image

Metro Attributes

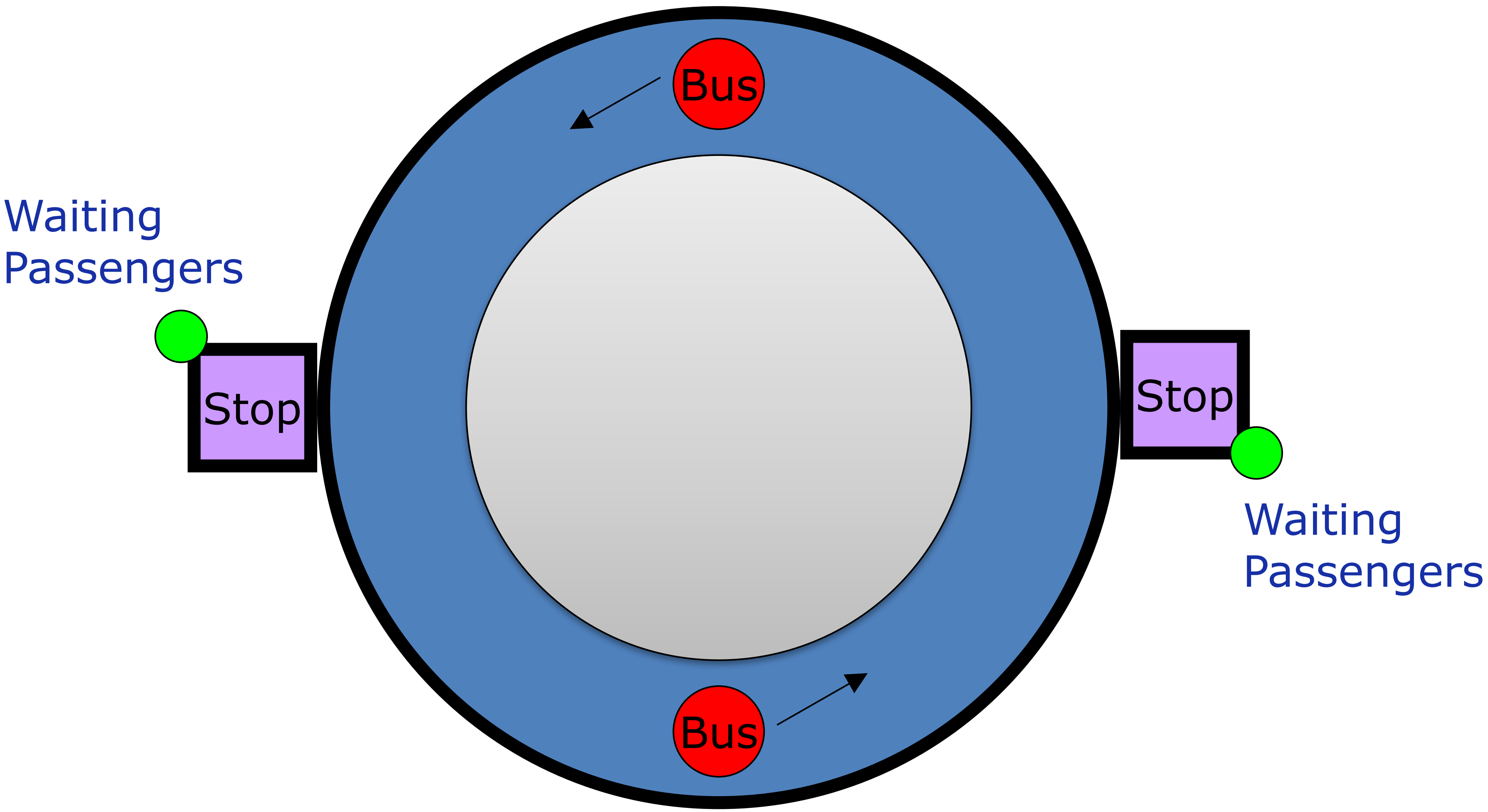
Main drivers

Actions



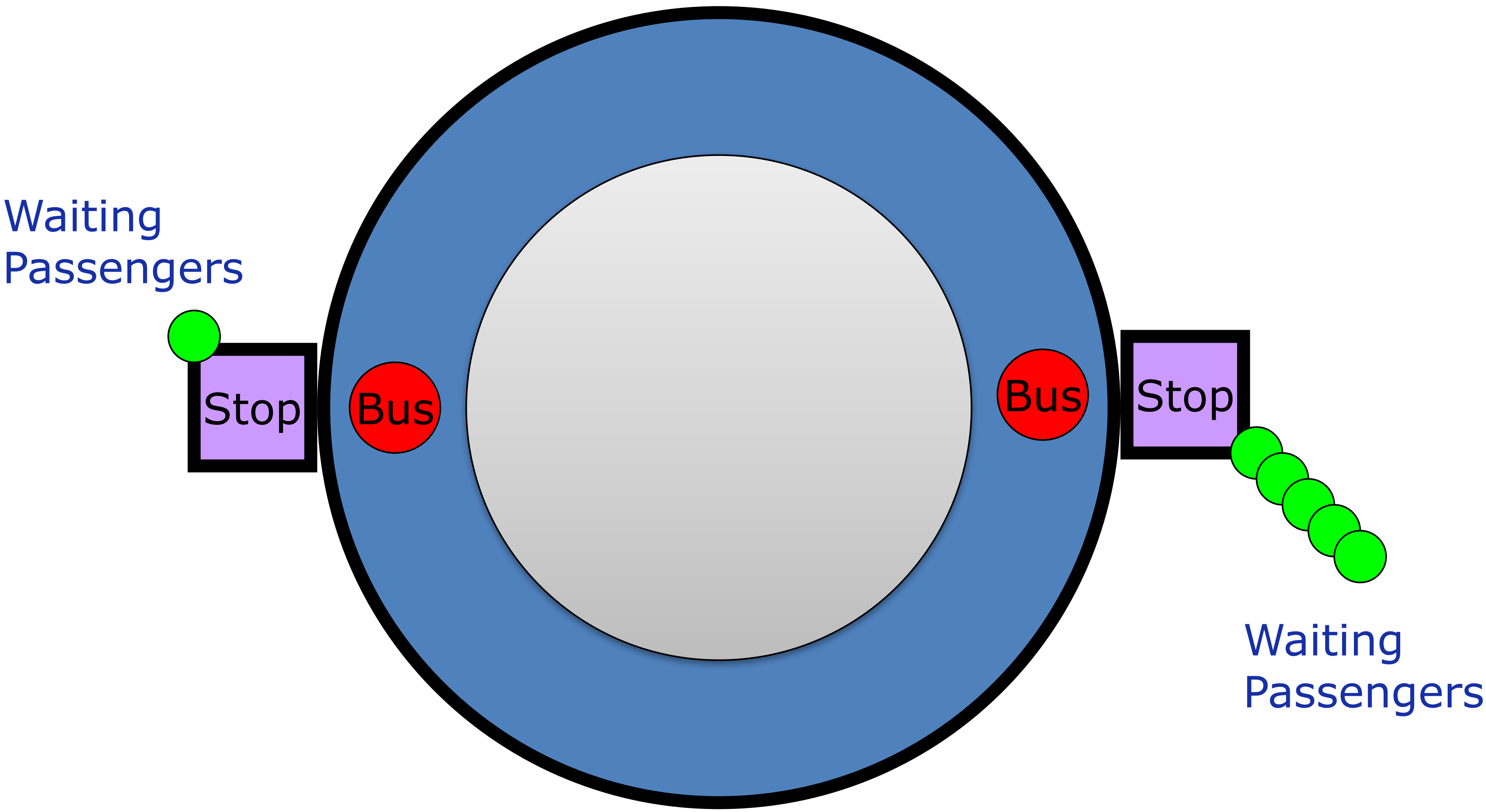
- Improved headway regularity

Bus Operations without Control



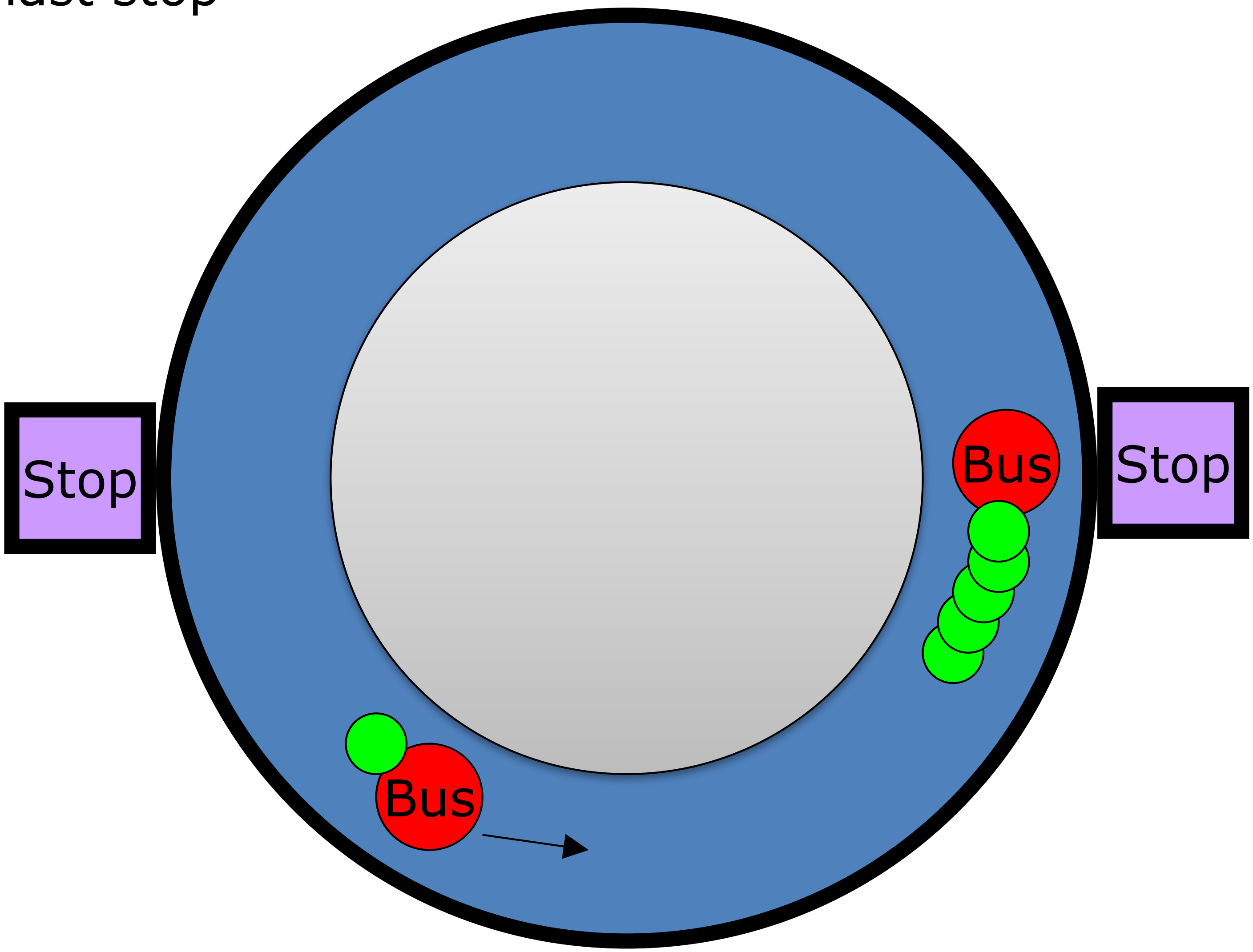
Bus Operations without Control

a small perturbation…

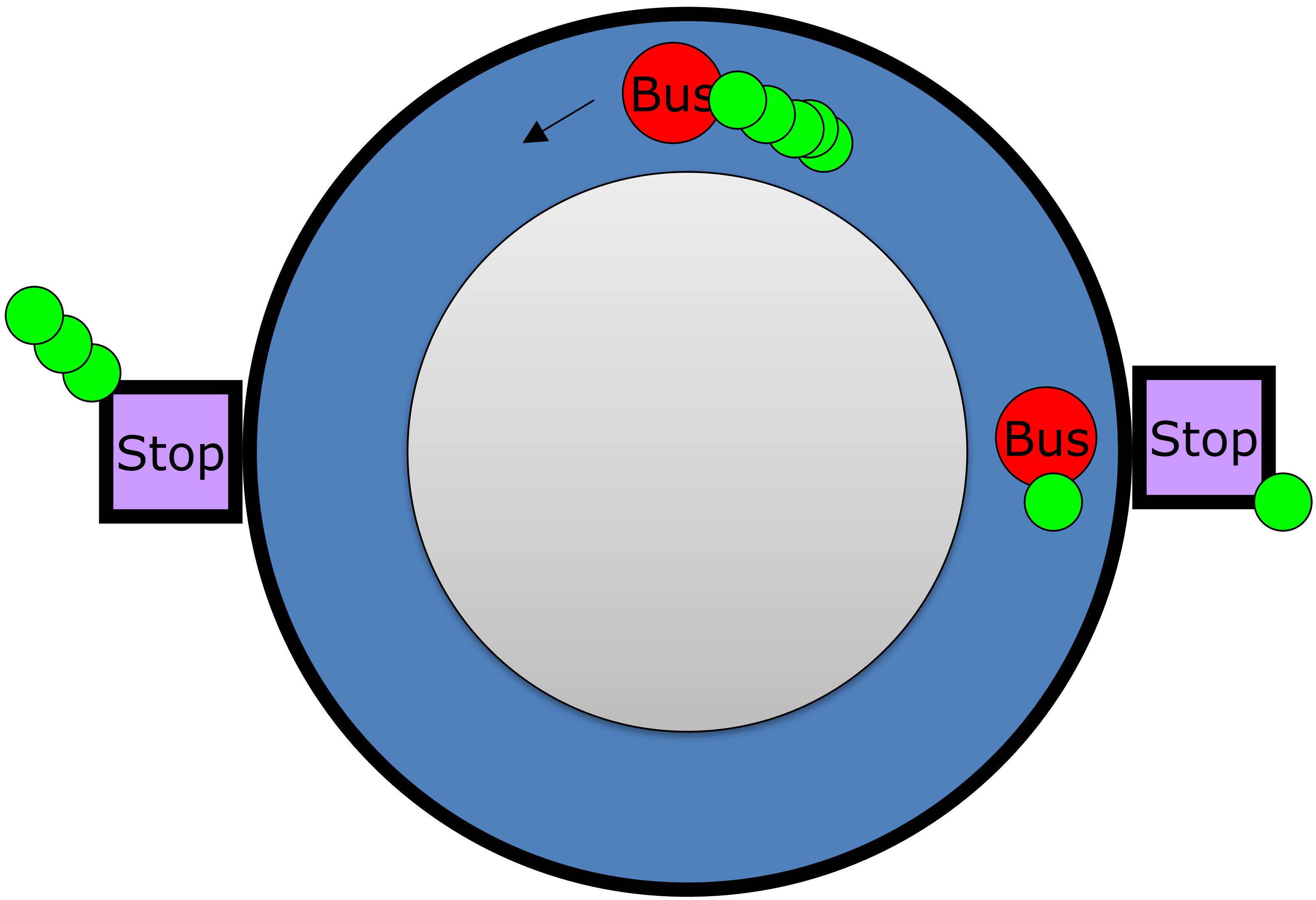


Bus Operations without Control

While one bus is still loading passengers the other bus already left its last stop

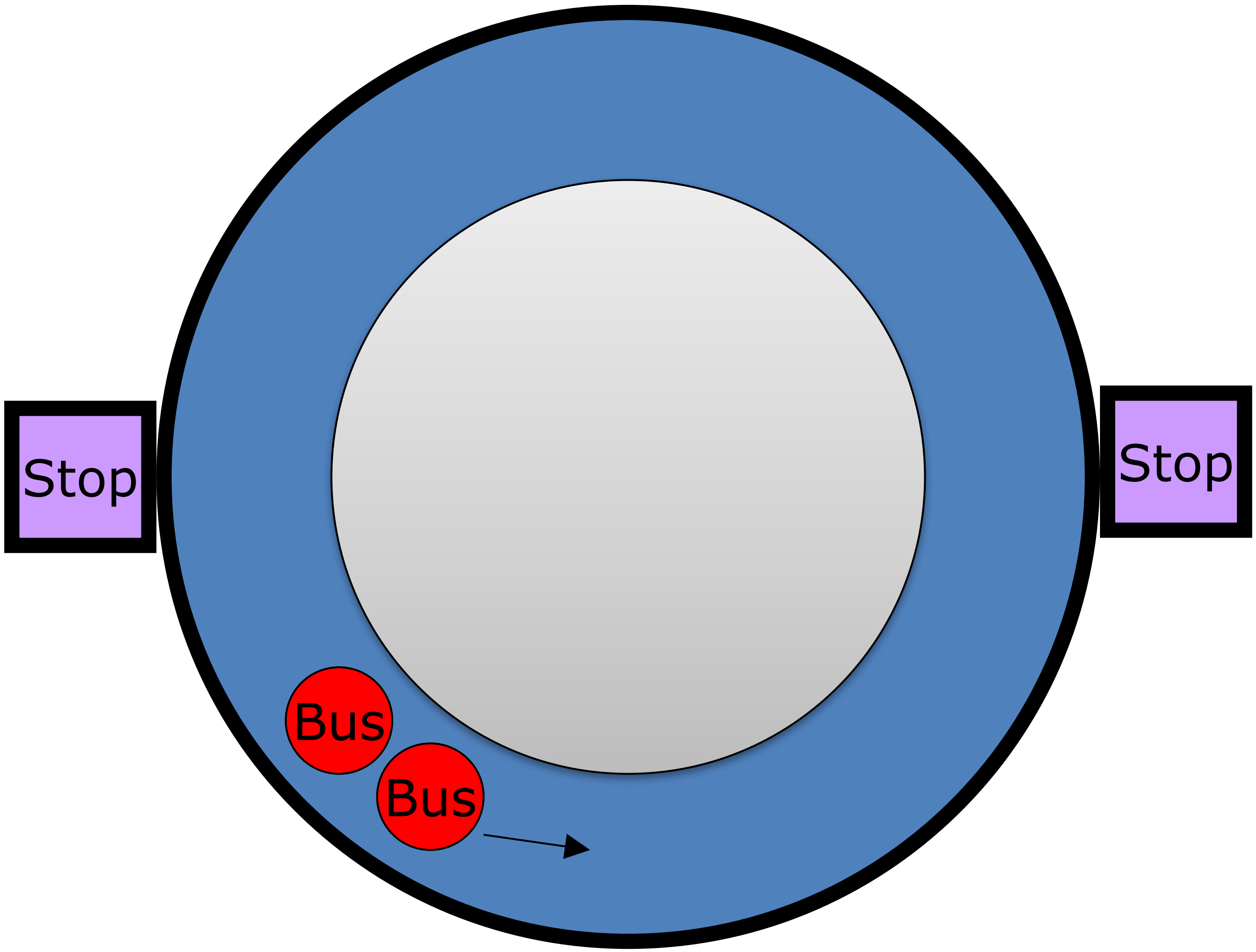


Bus Operations without Control



Bus Operations without Control

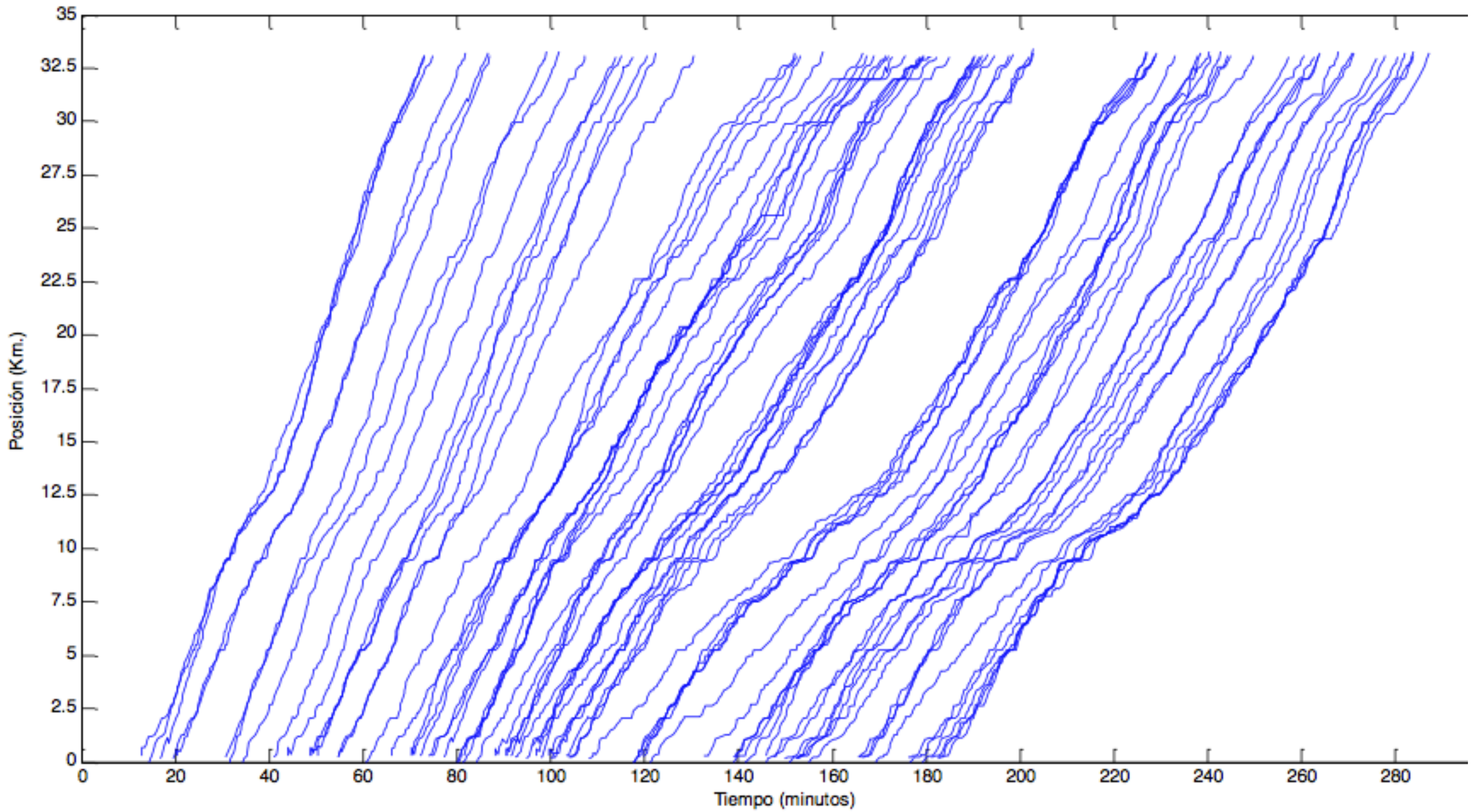
Without bus control, bus bunching occurs!!!



Transantiago, Santiago, Chile


Cambridge, MA
1 VIA MASS
1 DUDLEY STA
Height 11'4"
Environmentally Friendly Fuel
2226
GET VACCINATED AND HELP PREVENT THE SPREAD OF FLU.
WWW.BPHC.ORG/FLU
2226

Time-space trajectories Line 210



Bus bunching is a severe problem

- Most passengers wait longer than they should for crowded buses
- Put pressure in the authority for more buses
- Reduces reliability affecting passengers and operators

Idea: Control Strategies to Avoid Bus Bunching!

Solving Bus Bunching: Schedule Control

- Buses have to adhere to static schedules in stops or control points
- Useful for low frequency (<5 buses/hour) lines without congestion: not the reality of major urban cities.
- KPI:
  - Punctuality indicator that measures the adherence to a schedule.
- Pros:
  - Easy to implement & to understand by driver.
  - Transparent for users.
- Cons:
  - Not useful for high frequency or congested lines
  - Excessive slack in schedules

Solving Bus Bunching: Headway Control

- Dynamic suggestions to increase/decrease speed & holding at stops and terminals
- Several control strategies in the literature, lately some developed & implemented:
  - Recent advancements on ICTs
  - Lower hardware & communication costs
- Challenges:
  - Making a smart solution robust enough to scale
  - Driver compliance
- KPI:
  - Headway deviation in control points along the route
  - Waiting times, Bus loads
  - Santiago: ICR & regularity fines

Previous Work on Holding Strategies

Turnquist and Blume (1980) pioneer work on threshold policy for holding buses

Reference	PH	PD and RT	Overtaking	OF	Veh. Cap.	Control Points	Buses	Sol. method
Ding y Chien (2001)	Multiple	Deterministic	Prohibited	V_h	ignored	CMS	One	OPT
Eberlein et al (2001)	Multiple	Deterministic	Prohibited	W_{first}	ignored	PSS	Multiple	Heuristic
Hickman (2001)	One	Stochastic	Allowed	$W_{first}+W_{in\text{-}veh}$	ignored	PSS	One	OPT
Zhao et al (2003)	One	Stochastic	Prohibited	$W_{first}+W_{in\text{-}veh}$	ignored	CMS	One	Heuristic
Sun y Hickman (2004)	Multiple	Deterministic	Prohibited	$W_{first}+W_{in\text{-}veh}$	ignored	PMS	Multiple	Heuristic
Zolfaghari et al (2004)	Multiple	Deterministic	Prohibited	$W_{first}+W_{extra}$	considered	CSS	Multiple	Meta-heuristic
Puong y Wilson (2004)	Multiple	Deterministic	Prohibited	$W_{first}+W_{in\text{-}veh}+W_{extra}$	considered	CMS	Multiple	OPT

New Idea: Boarding Limits

Innovations

1.- Decision variables:

Holding

Boarding Limits

This can be used even when at less than physical capacity in order to increase operating speed.

Passengers prevented from boarding

Passengers allowed to board

2.- Bus capacity incorporated without resorting to binary variables

System Characteristics

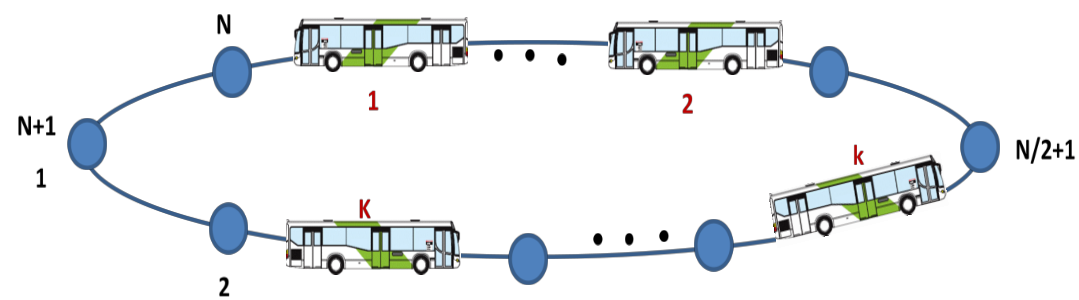
The system is composed by:

One-way loop Transit corridor.

Operated by a single service.

N stops.

K homogeneous buses.



State Variables

Real Time information about:

Bus position.

Bus loads.

# of Passengers waiting at each stop.

However, we could work with estimations…

and in practice there is no alternative

Model: Assumptions

Some information about trip destinations.

Dwell time: dominated by boardings.

Buses serve all stops and overtaking is not allowed.

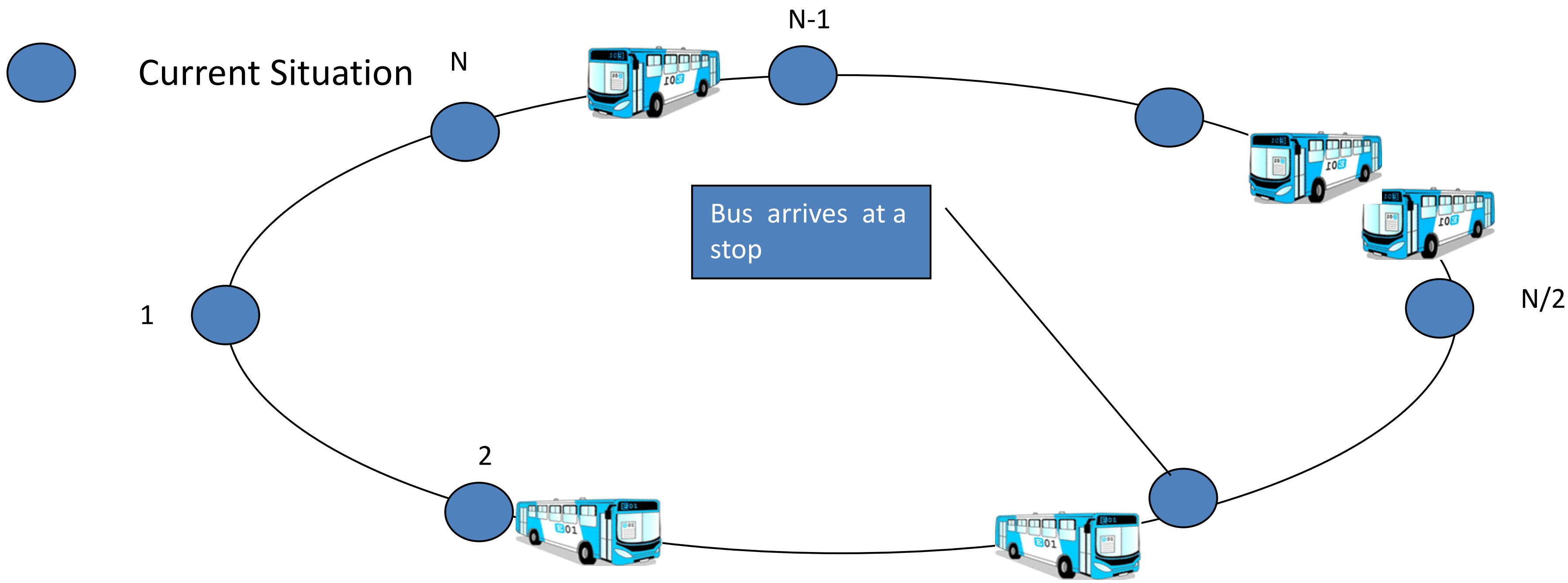
Model: Problem definition

Every time a bus reaches a stop:

How much to hold it?

Should we prevent some passengers from boarding?

Solve a rolling horizon optimization problem to take those single decisions



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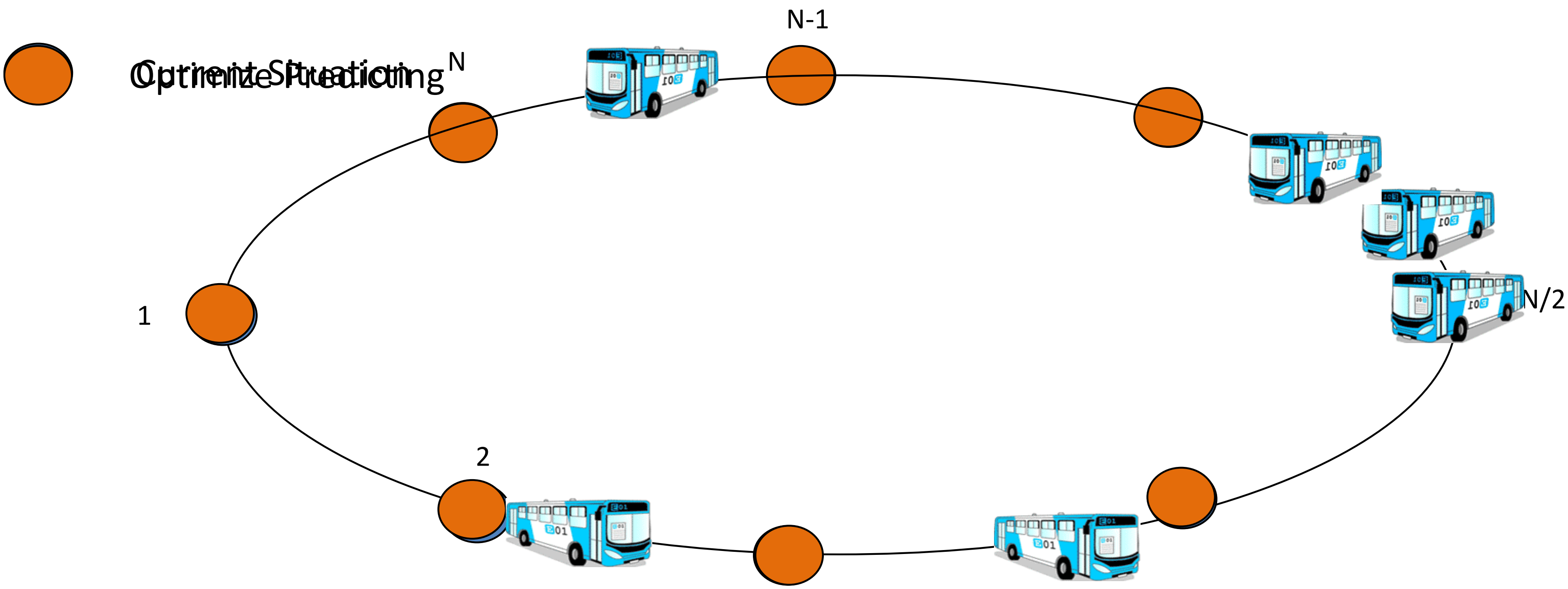

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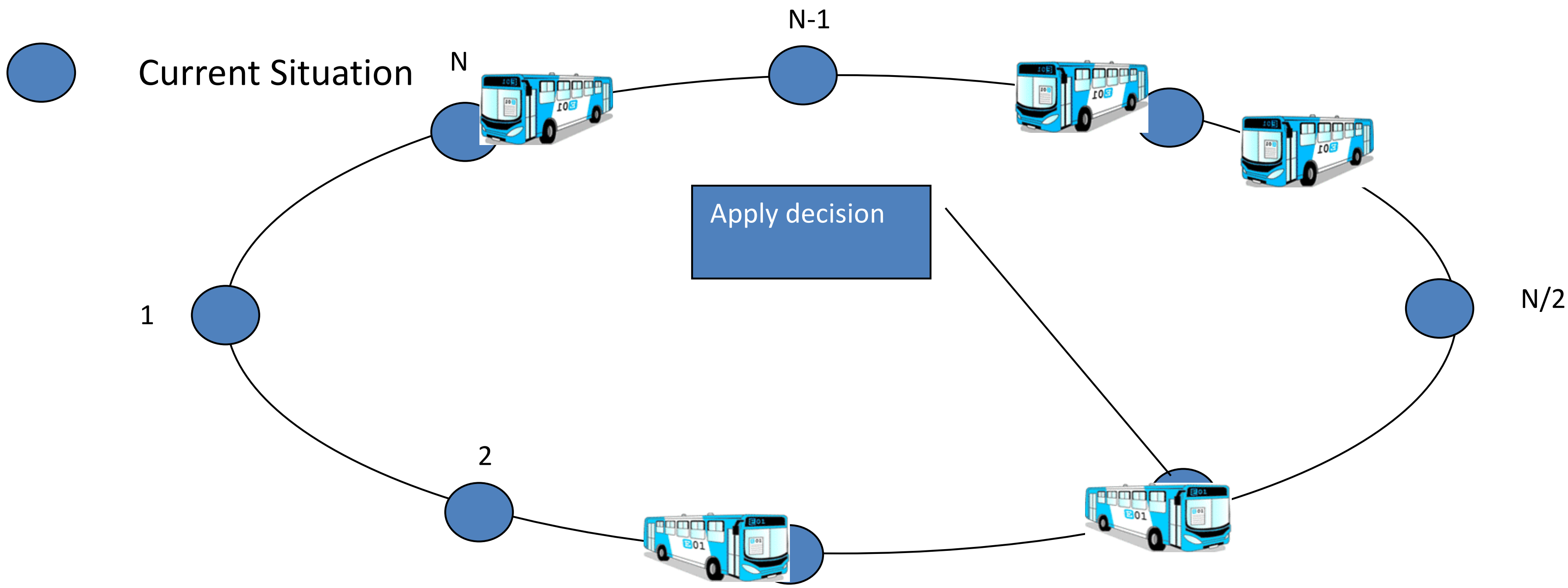


3. Model: Objective Function

$$\underset{h_{kn}, w_{kn}}{Min} \quad \theta_1 \cdot W_{first} + \theta_2 \cdot W_{in-veh} + \theta_3 \cdot W_{extra} + \theta_4 \cdot PE$$

Experiment: Simulation Scenarios

High frequency transit system scenario (headway ~2min.)

High passenger demand (bus capacities can be reached)

One-way loop Transit corridor with 30 Stops and 29 Traffic Lights (in both ways)

Competing flow 700 veh/h

Main flow 900 veh/h

Saturation flow 1800 veh/h

Parameter	Value	
Cycle time	72	sec
Green time for bus approach	40	sec
Offsets between traffic lights	23	sec
Maximum extension	4	sec

Experiment: Simulated Strategies

No control

Spontaneous evolution of the system.

Buses are dispatched from the terminal as soon as they arrive or until they reach the designed headway.

No other control actions are taken along the route.

Proposed Model

Solve the rolling horizon optimization model **including** holding, boarding limits and green extension

5. Simulation Results

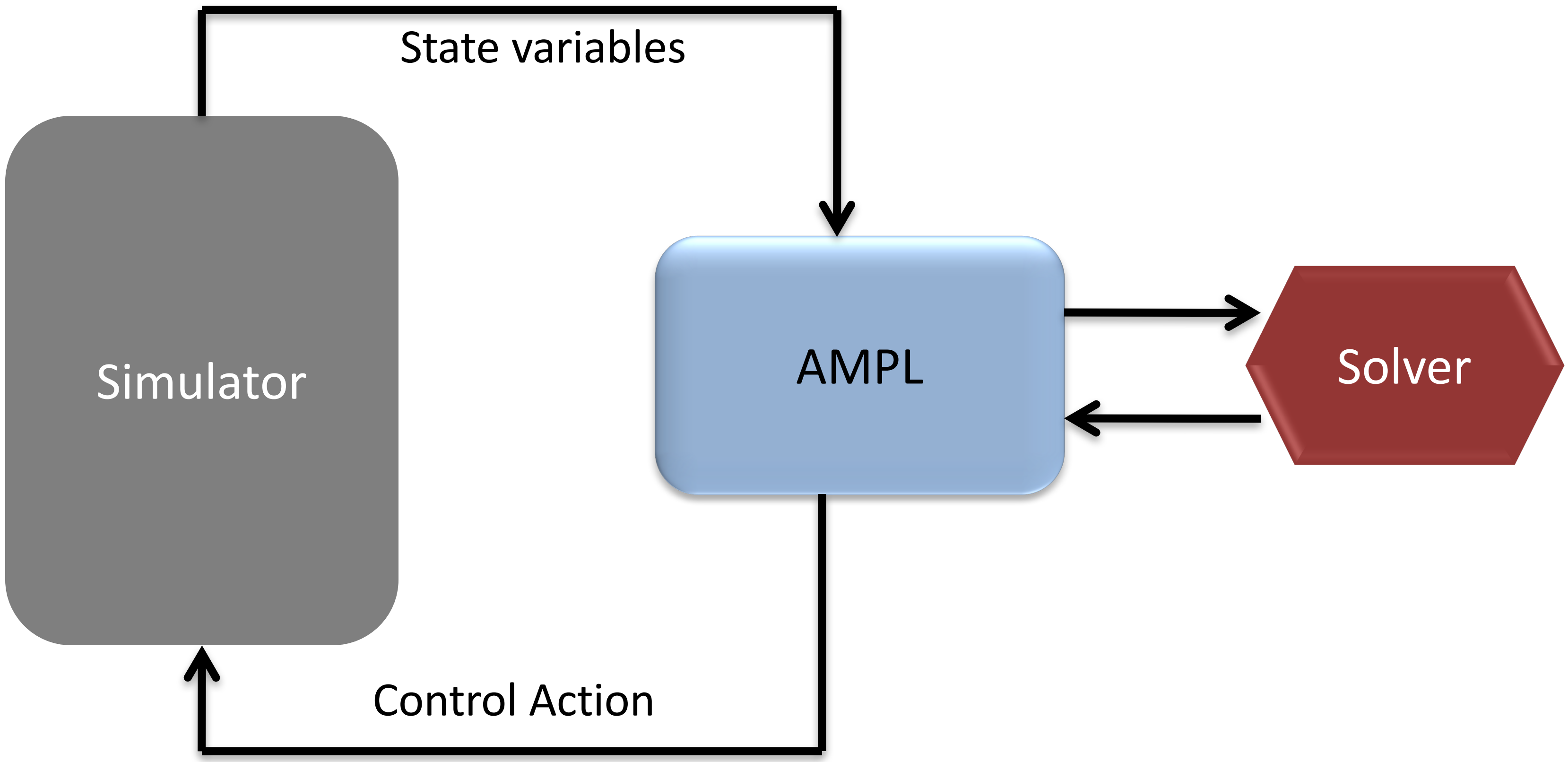
30 runs for every combination of strategies and scenarios

Each run represents 2 hours of bus operation.

15 minutes "warm-up" period.

Variability is introduced in the simulation experiment.

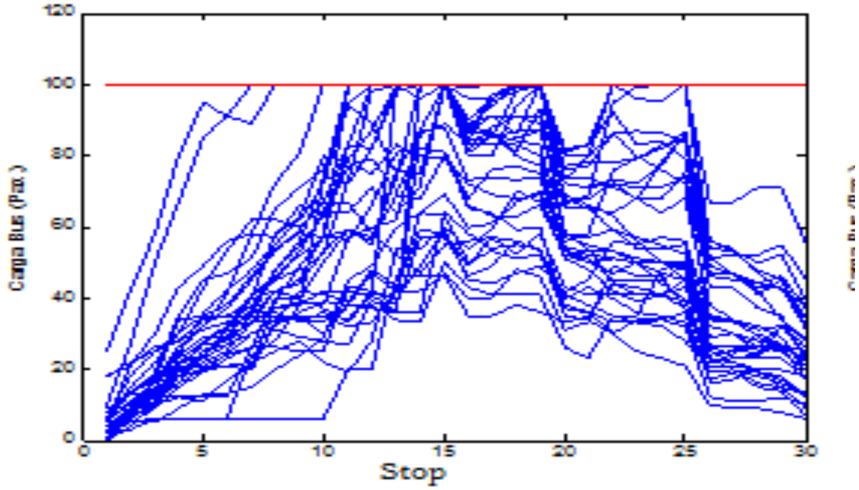
Results: Simulation Framework



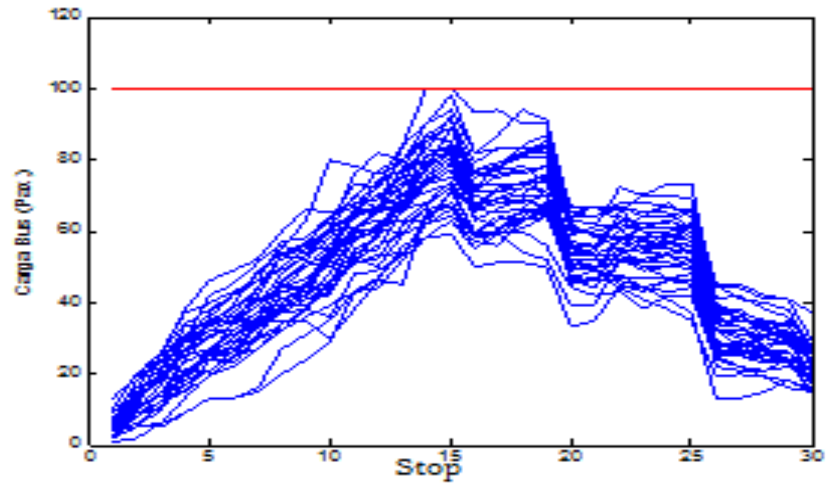
Simulation Results: Transit Users

	No Control	Proposed
W_{first}	7636.32	1438.62
Std. Dev.	649.36	146.56
% reduction		-81.16
W_{extra}	6218.71	1010.52
Std. Dev.	2265.24	82.04
% reduction		-83.75
$W_{in\text{-}veh}$	175.32	1561.34
Std. Dev.	31.69	77.3
% reduction		790.55
W_{t_light}	4052.81	2965.1
Std. Dev.	88.27	110.27
% reduction		-26.84
Total	18083.16	6975.58
Std. Dev.	2600.63	275.12
% reduction		-61.42

Simulation Results: Bus Loads

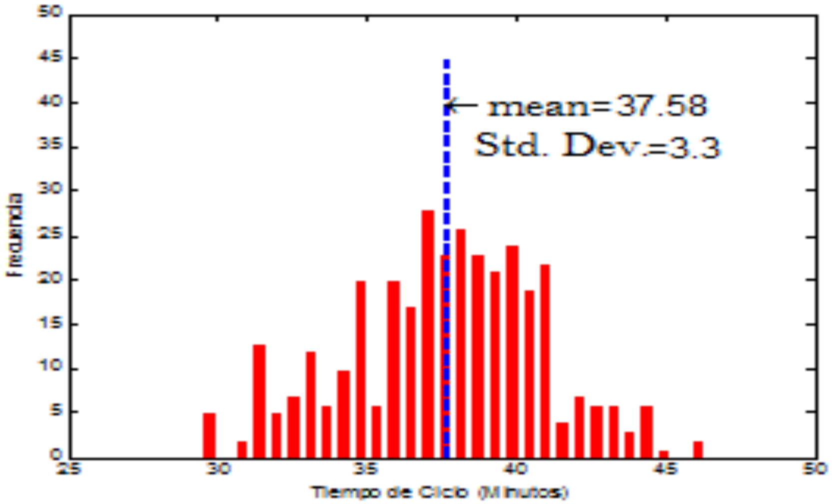


a) No control

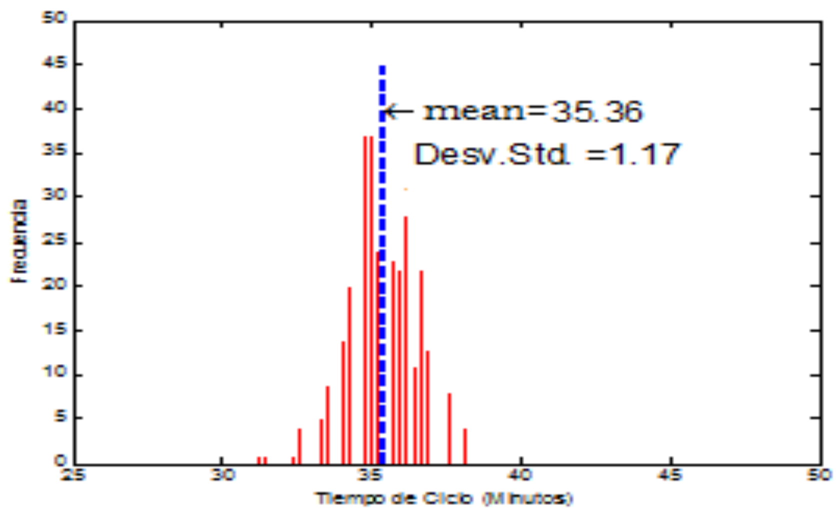


c) Proposed

Simulation Results: Cycle Times



a) No control



c) Proposed

Results: Vehicle cap. constraints & medium frequency

	% of passengers that have to wait between:		
	0-5 min.	**5-10 min.**	**more than 10 min.**
No control	78.90	17.52	3.58
Treshold control	89.26	9.80	0.95
HRT	92.46	7.50	0.04
HBLRT	93.74	6.19	0.07

Research Conclusions

- We have a tool for effectively reducing bunching of buses in a BRT.
- The tool is fast enough for real-time applications.
- The proposed control strategy outperform simple control rules with saving up to 61.4% for transit users.
- Boarding Limits are only attractive in high demand and high frequency scenarios.
- Severely improve comfort and reliability for transit users.
- Reduction on vehicle cycle times allow for reductions on fleet size or improvements on level of service.

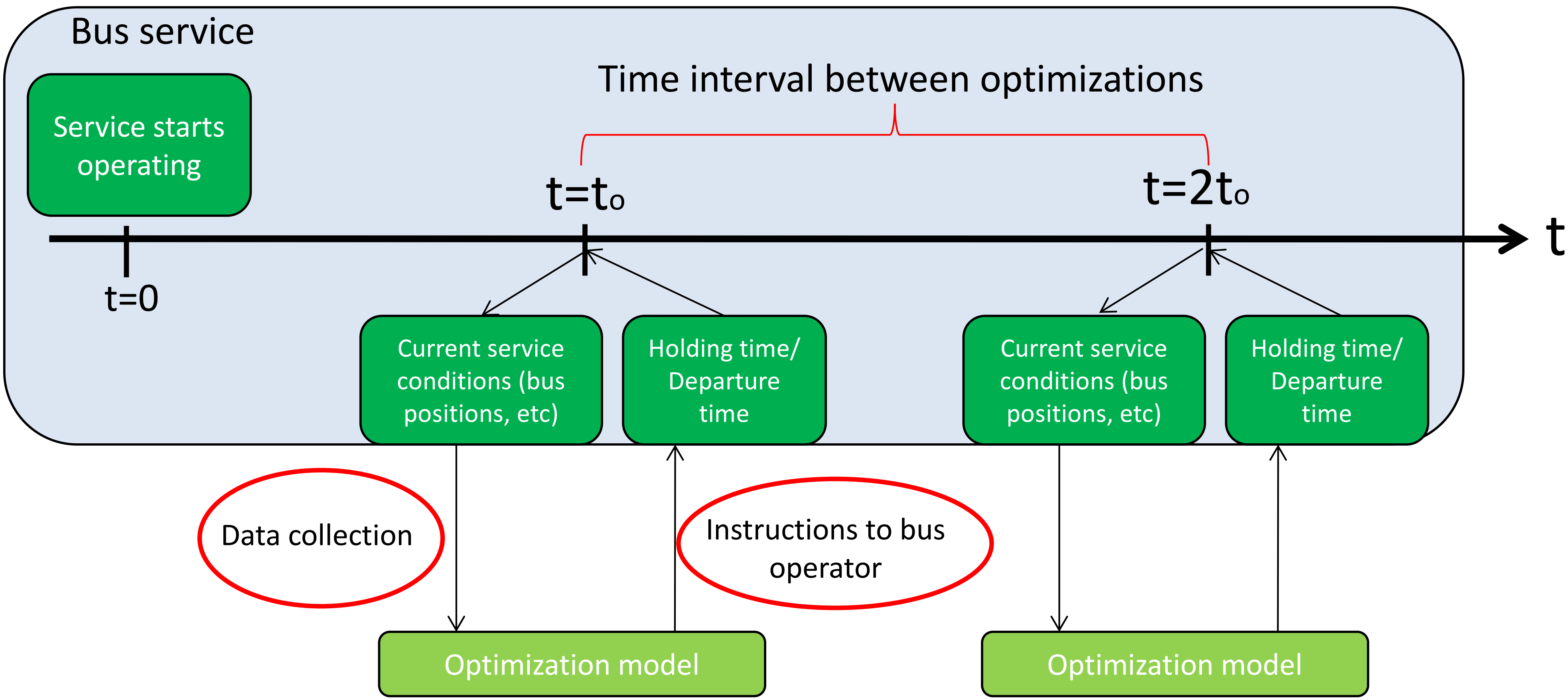
We should do it!

Pilot Project Context

- In 2012 a fine scheme was implemented in the Santiago transit system (Transantiago):
  - ✓ Guarantee frequency and regularity compliance
  - ✓ Regularity fines if bus headway exceeds threshold
  - ✓ Average monthly system fines (2012): $USD 2.3 million

- The fine scheme evidenced the lack of available tools in the market to regularize headways on high frequency services

How does the model operate?

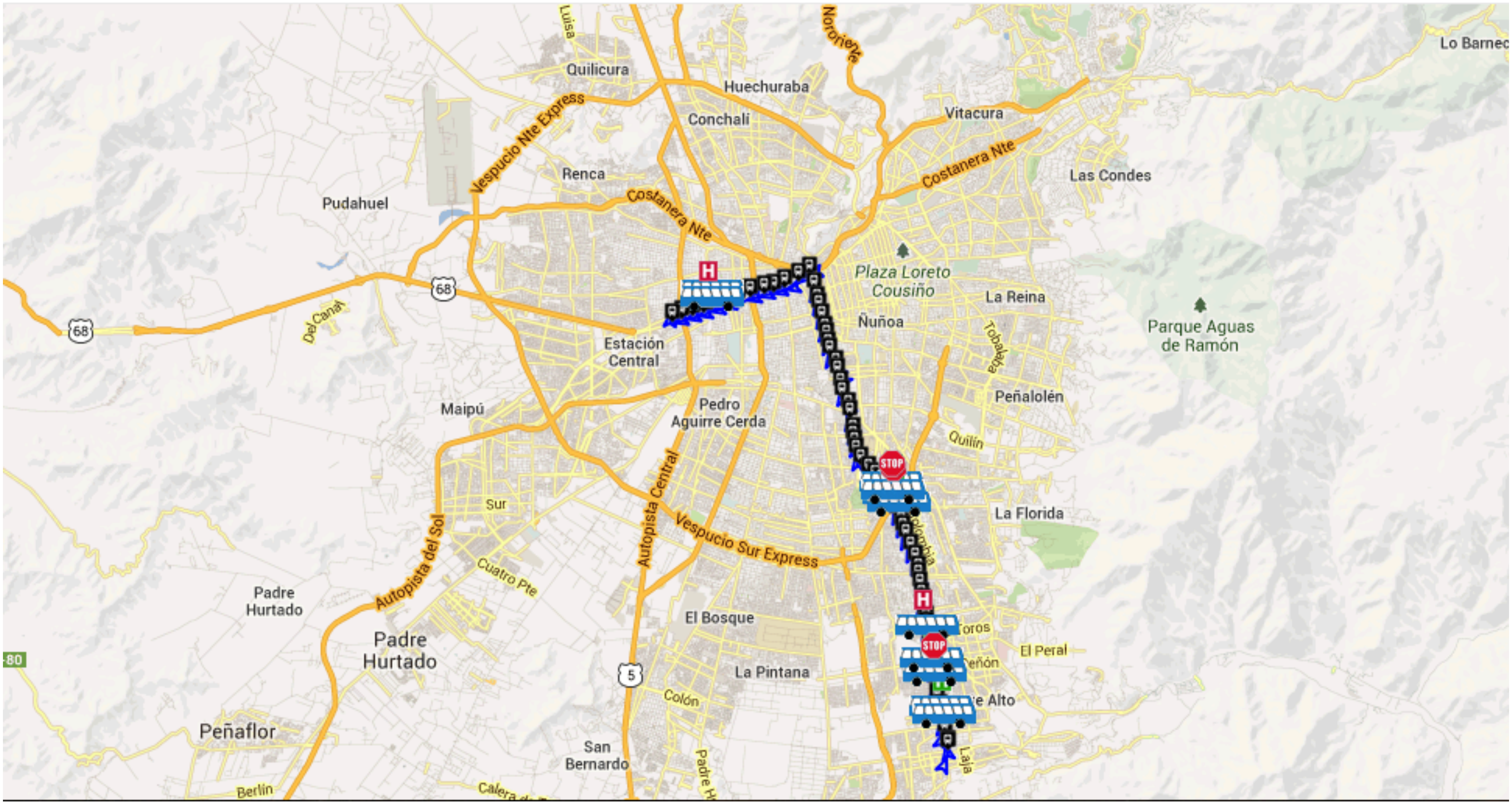


Pilot studies

- Due to the success of the model in simulation environment, a Santiago bus operator company was willing to try.
- Pilot studies with service 210 (Subus Chile):
  - ✓ November 2012 (Pilot 1) and April 2013 (Pilot 2)

210 Pilot Plan

- Example of bus bunching in 210 service:



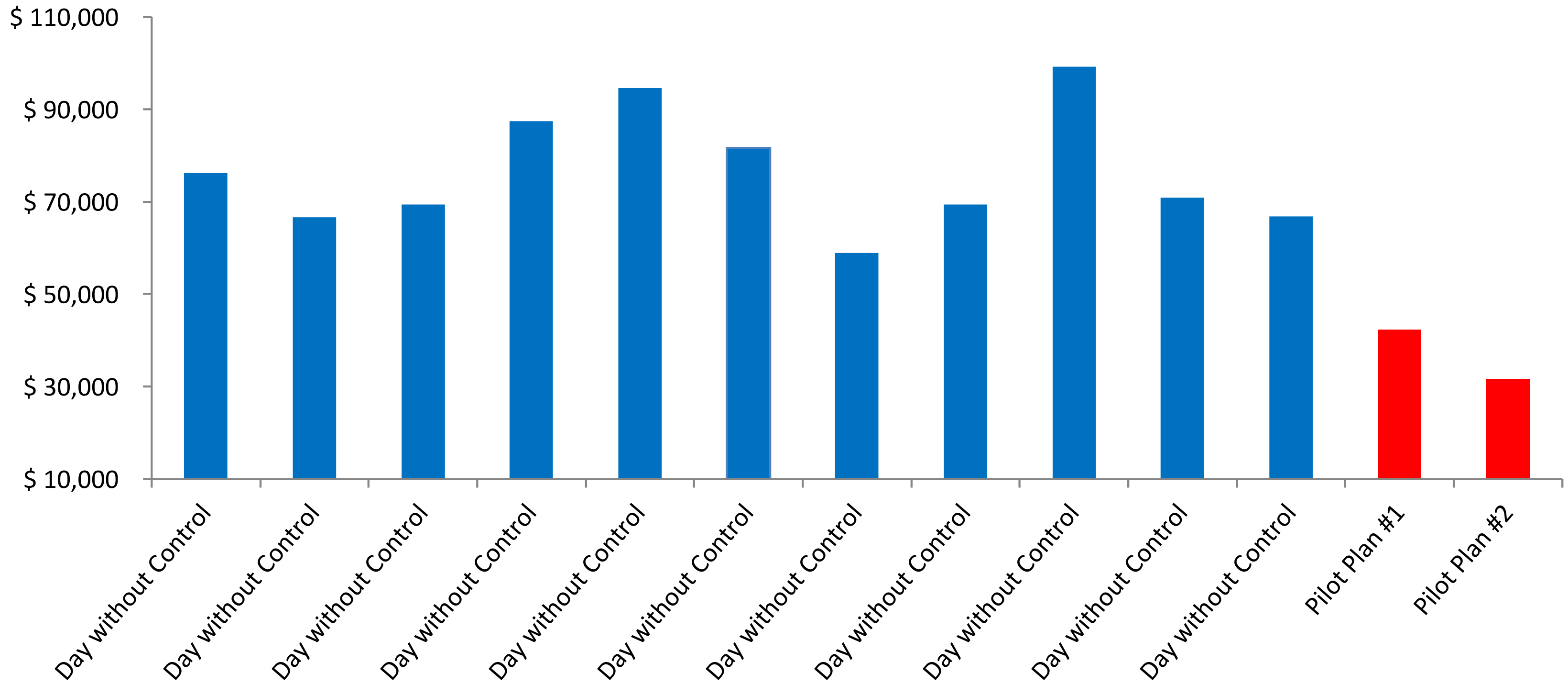
Service 210 Characteristics

- High demand (48,000 passengers/day)
- High frequency service (a bus every 3-4 minutes)
- Complete route (inbound+outbound):
  135 stops and 56 km long
- In morning peak: up to 60 buses operating in service
- One of the worst service in terms of user evaluation of Transantiago
- Service with high fare evasion

Pilot studies

Pilot studies: results

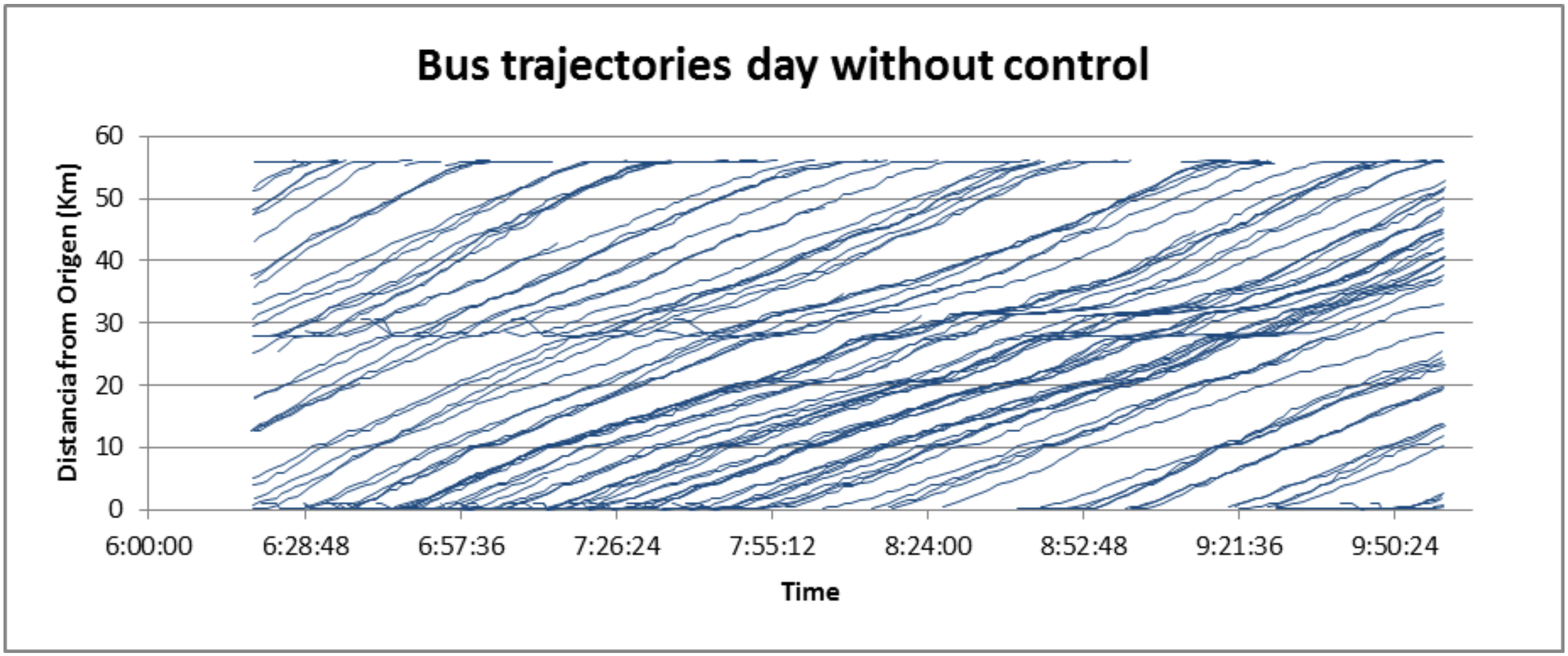
- Morning peak period (6:30-9:30) fines 210-outbound service ($CLP):



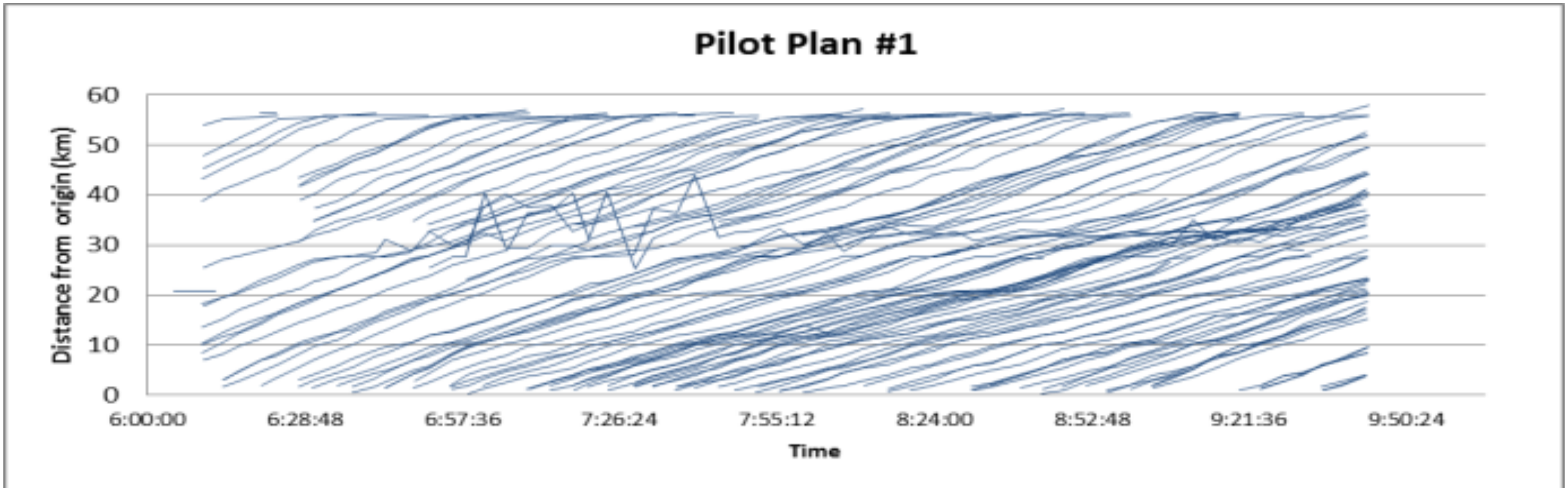
USD 1 = CLP 670

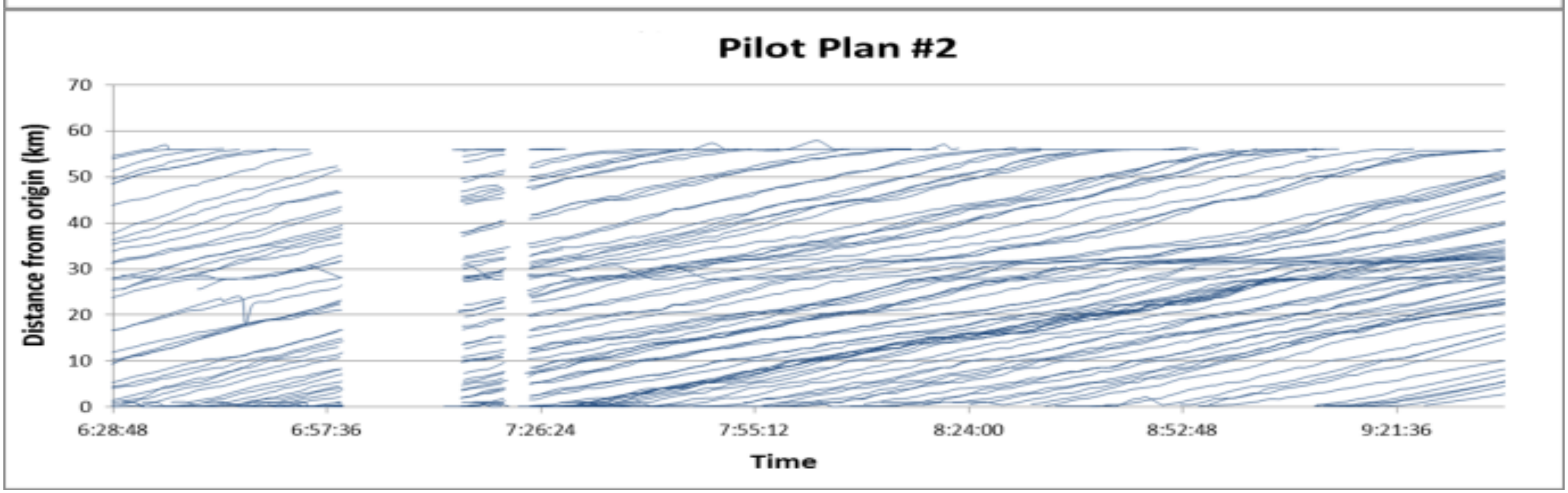
Pilot studies: results

Bus trajectories (distance vs time) day without control



Pilot studies: results





Pilot studies: results Line 210

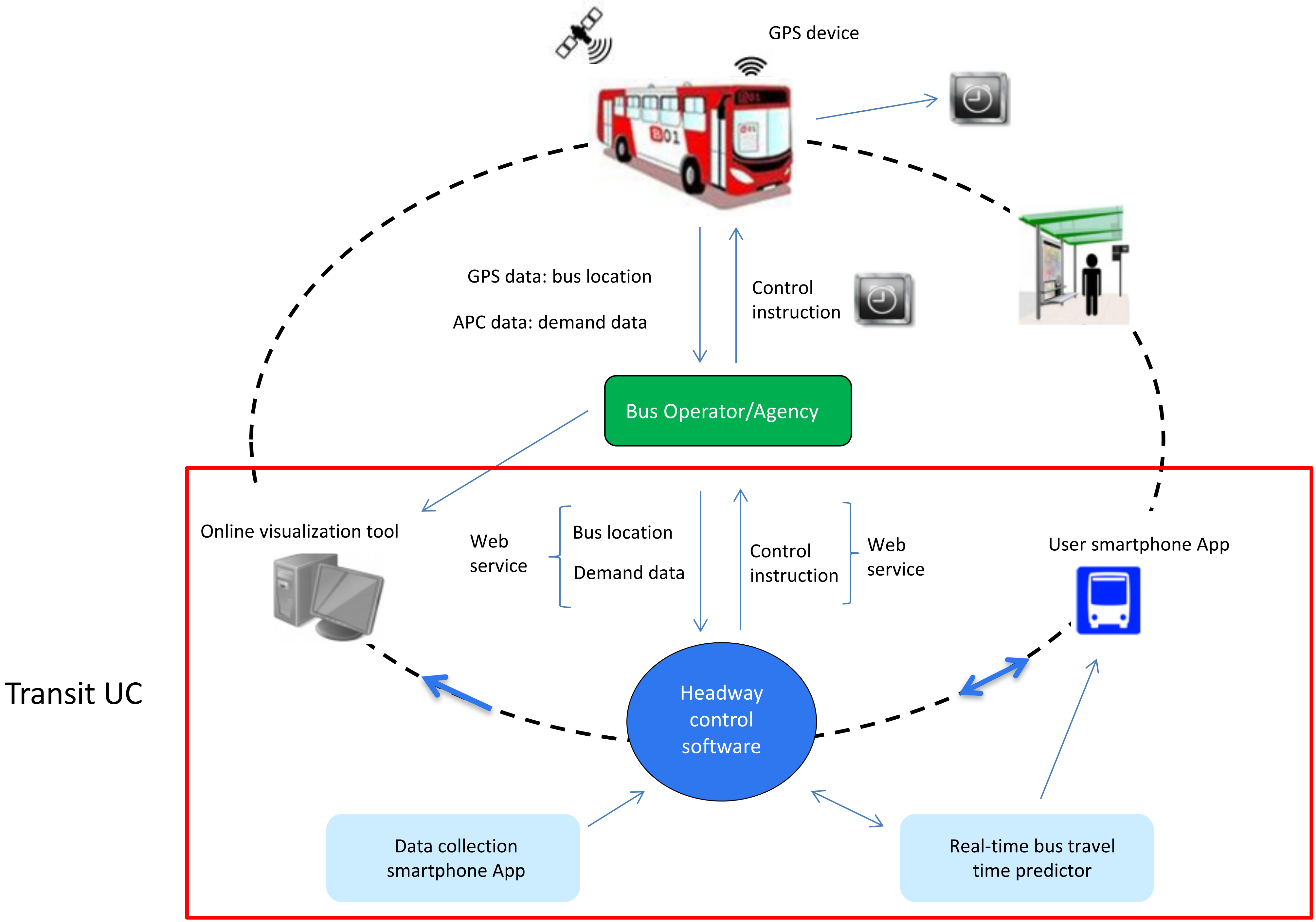
- Surprisingly, user validations (demand) increased by 20% during the pilot plans
  - Reduction of user evasion: “passive evasion”
- No significant effects on bus frequency and cycle times

TransitUC

INNOVATIVE TECHNOLOGICAL SOLUTIONS FOR TRANSIT SYSTEMS

Felipe Delgado, Ricardo Giesen, Juan Carlos Muñoz

Pedro Lizana



GPS device
GPS data: bus location
APC data: demand data
Control
instruction
Bus Operator/Agency
Online visualization tool
Web
service
Bus location
Demand data
Control
instruction
Web
service
User smartphone App
Transit UC
Headway
control
software
Data collection
smartphone App
Real-time bus travel
time predictor

Technological Pilot Plans

- Objective: Send control instructions directly to bus driver using a bus console-tablet
- Subus-Chile (210 service)
  - ✓ Control instructions: holding buses at stops and skip stops
  - ✓ They already have industrial consoles installed in their buses: used with a itinerary-based control system that has been ineffective in peak periods

Software input information

- Static transit system data:
  - Bus services, operating programs, bus stop locations, etc.: data in format General Transit Feed Specification (GTFS)
- Real-time bus positions:
  - GPS already installed in buses
  - Tablet App GPS
- Demand data:
  - Passive smart card information: OD matrices and bus stop arrival rates
- Segment speeds:
  - Combination of real-time speeds (from GPS data) with historical speeds: research on Artificial Neural Network (ANN) and Bayesian Networks algorithms

210 Pilot Plan – Bus console

210 Pilot Plan – Bus console

- Screenshot of holding instruction at bus stop:

Current stop

Holding time countdown

Copyrights: Mobius

210 Pilot Plan – Bus console

- Screenshot of holding instruction not carried out by bus driver:

Help a more regular operation: depart stop at indicated time

210 Pilot Plan: Technical Challenges

- Some buses have GPS data delayed in up to 3 minutes (with a GPS pulse every 30 seconds): Hard to predict where the bus is currently located.
- Very rigid console App (developed by other company): in some cases the console does not connect and no sugestions are displayed to drivers.

210 Pilot Plan- Human Challenges

- Some drivers like to bunch up with previous buses so few people load their buses and work shorter shifts
- Some drivers bandalized their consoles: company had to put a plastic layer on top of the screen (not anymore touchscreen)
- Users frustated by the current level-of-service that do not like to be held at bus stops (drivers threatened to be beaten by users; users kicking bus and windows; etc)

210 Pilot Plan: Company Challenges

- The company has an existing schedule-based control system (with very low credibility between drivers) that interacts with our headway-based system.
  - Possible confusion information to drivers
- Company did not provide any incentives for driver to improve regularity.

RESULTS PILOT TEST

TRANSMILENIO: DUAL 84

Pedro Lizana, CEO TransitUC

Ricardo Giesen

Service 84, Transmilenio


TM12A0018-CN101805
18:09
05/26 18:08
TP69: Salida inmediata de cabecera
CIÓN
Km/h
F1
F2
F3
F4
F5

How to measure regularity?

- Waiting time at stops can be expressed as:

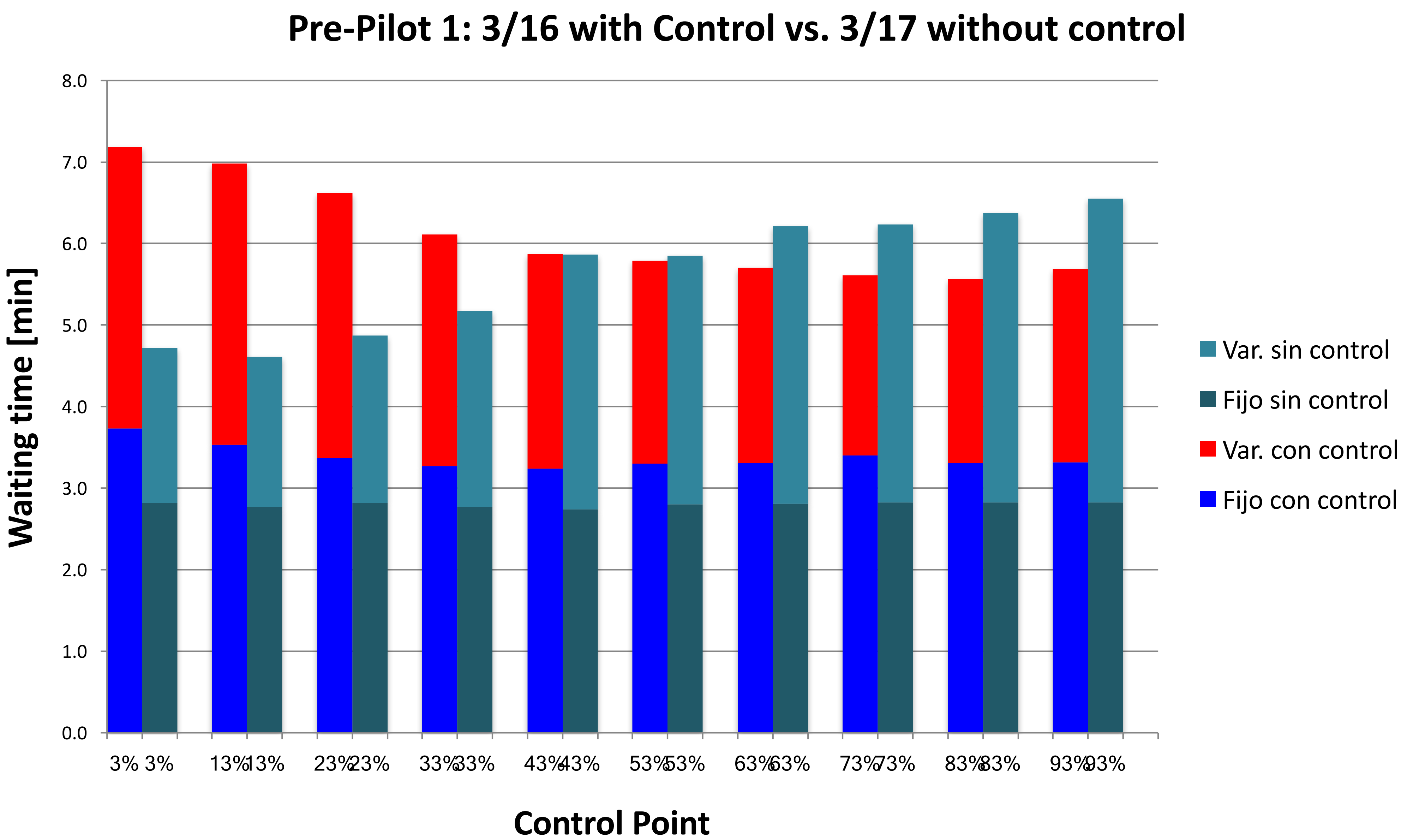
$$E(W) = \frac{E(H^2)}{2E(H)} = \frac{E(H)}{2} + \frac{Var(H)}{2E(H)}$$

- The first term depends on the frequency of buses (1/H), which is a function of the number of buses (n) and the cycle time (T_c).

$$H = T_c / n$$

- The second term depends on the variability of the headways between buses. This can be improved using *BuzzAssist*.

Transmilenio PrePilot Results



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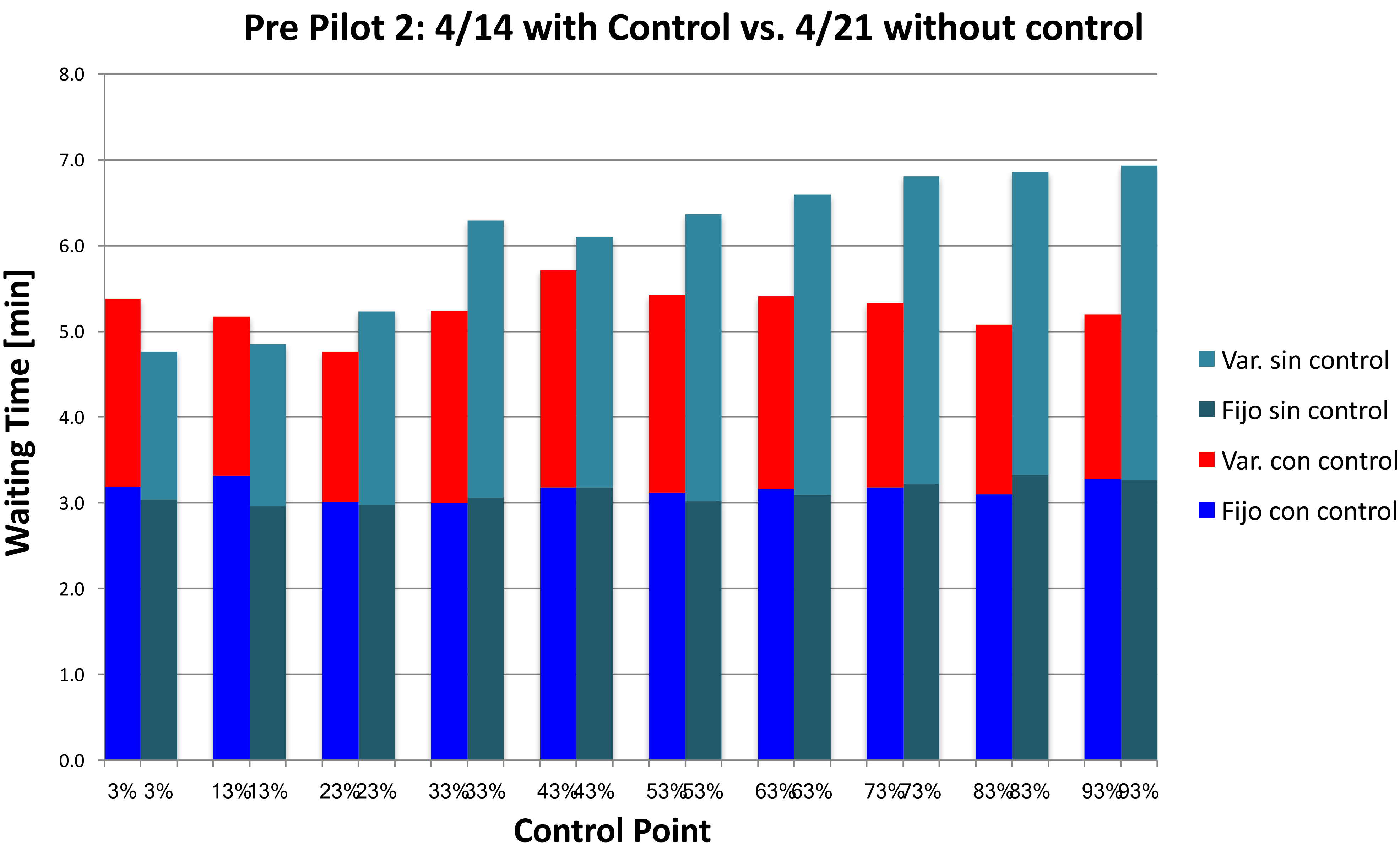
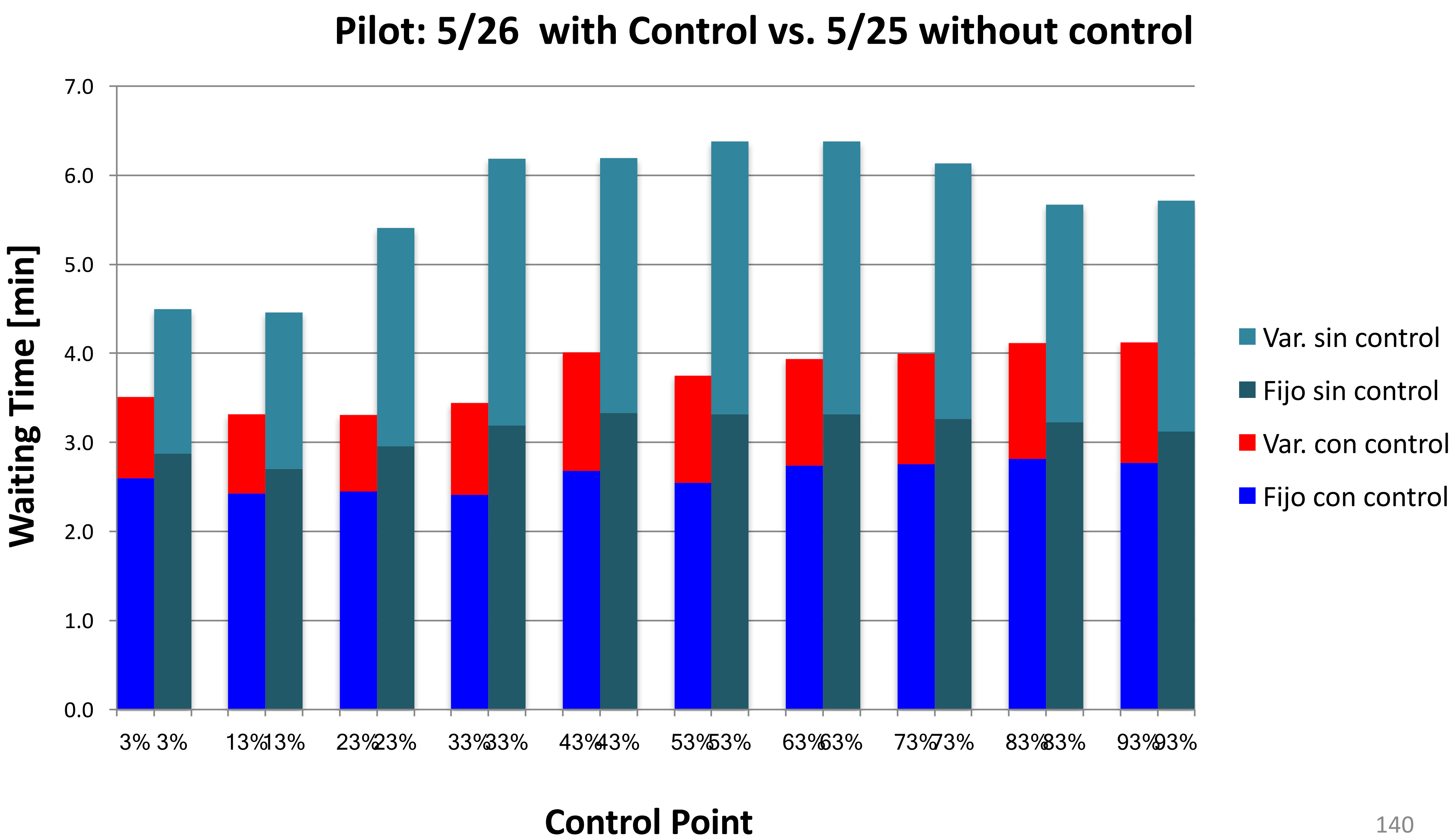
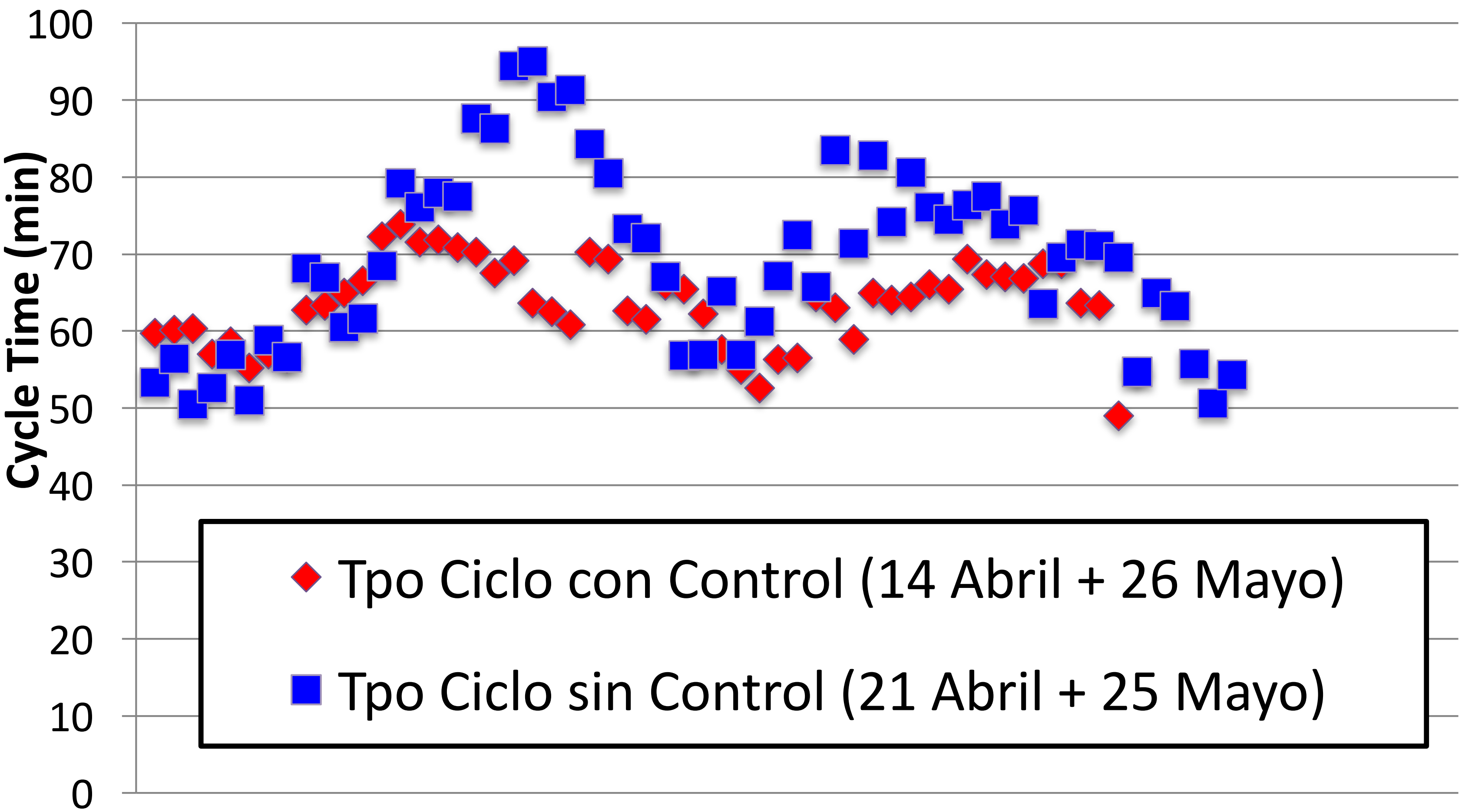


Transmilenio Pilot Results



Results: Cycle Time (one direction)



With control: Average Cycle Time = 63.4 min and St. Dev. = 5.6 min
Withoutcontrol: Average Cycle Time = 69.5 min and St. Dev. = 11.8 min

Promising results

- More regularity
- Less fines
- More demand
- However… drivers do not follow instructions, implementation challenges …

AVOIDING BUS BUNCHING

BusAssist

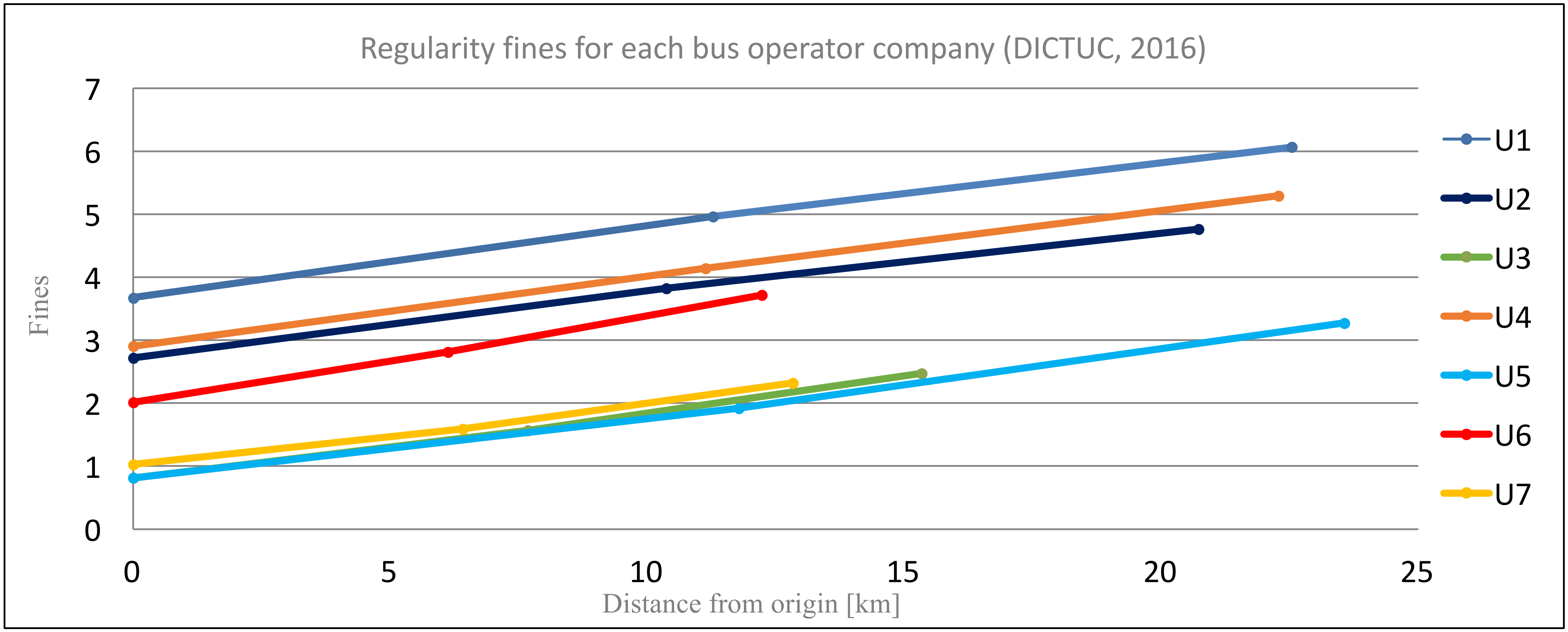
Developed App for Industrial Console to Provide Driver Assistance

BusAssist Implementation in Redbus, Transdev

- 61 lines and 600+ buses
- Approx. 300,000 daily paid trips (bip!) with ~ 25% fare evasion

TransitUC

Dispatching at terminals is not regular



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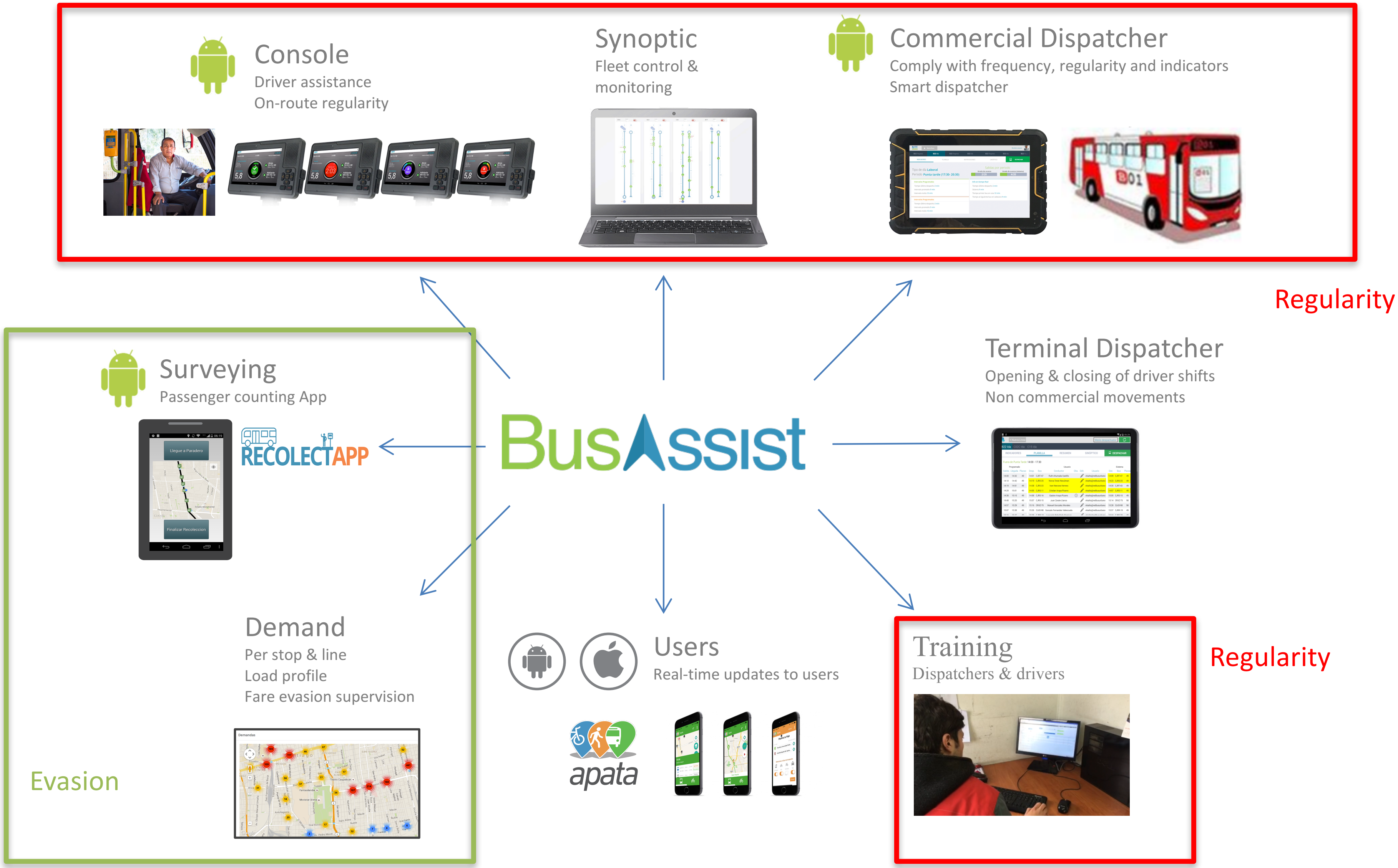
Console
Driver assistance
On-route regularity
Synoptic
Fleet control &
monitoring
Commercial Dispatcher
Comply with frequency, regularity and indicators
Smart dispatcher
Regularity
Terminal Dispatcher
Opening & closing of driver shifts
Non commercial movements
Surveying
Passenger counting App
RECOLECTAPP
BusAssist
Demand
Per stop & line
Load profile
Fare evasion supervision
Evasion
Users
Real-time updates to users
apata
Training
Dispatchers & drivers
Regularity

CAD/AVL

- Control center operators have access to a live synoptic to visualize buses, their bus bunching avoidance instructions, change their status and send messages to driver and dispatchers.

BusAssist

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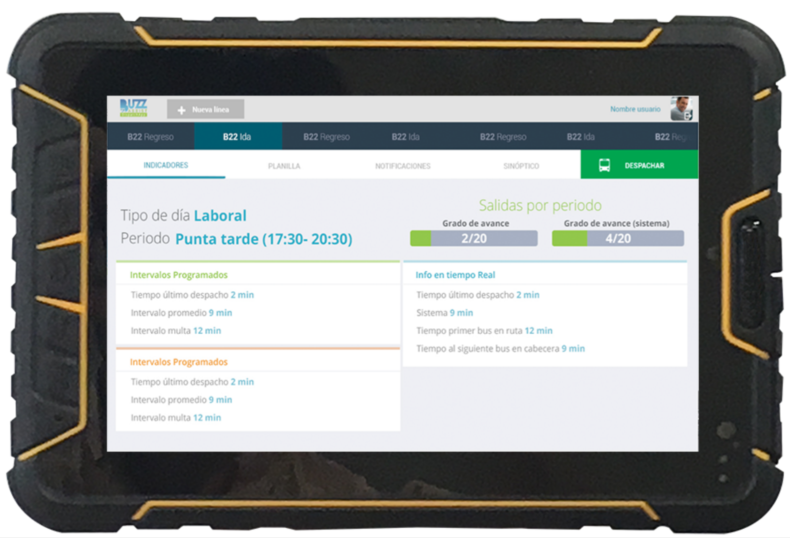
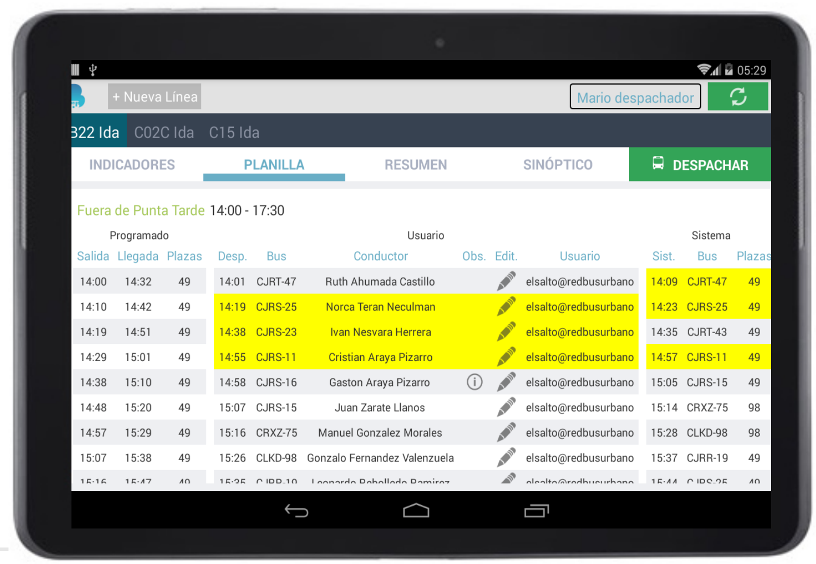
Smart dispatcher

- Dispatchers have access to a web and Android mobile app DispatchApp, that informs them of real-time regularity indicators and gives them smart dispatch time suggestions in order to increase the regularity of each line.





BusAssist

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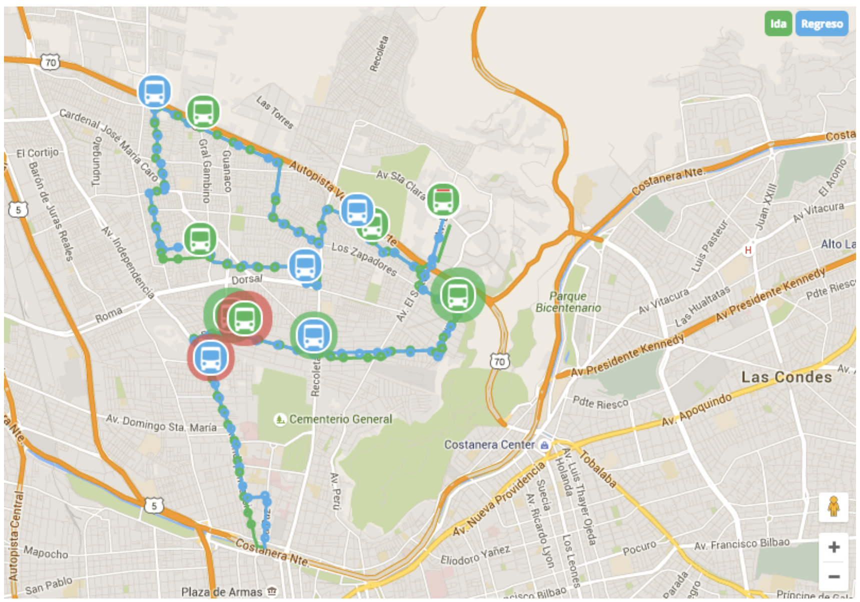
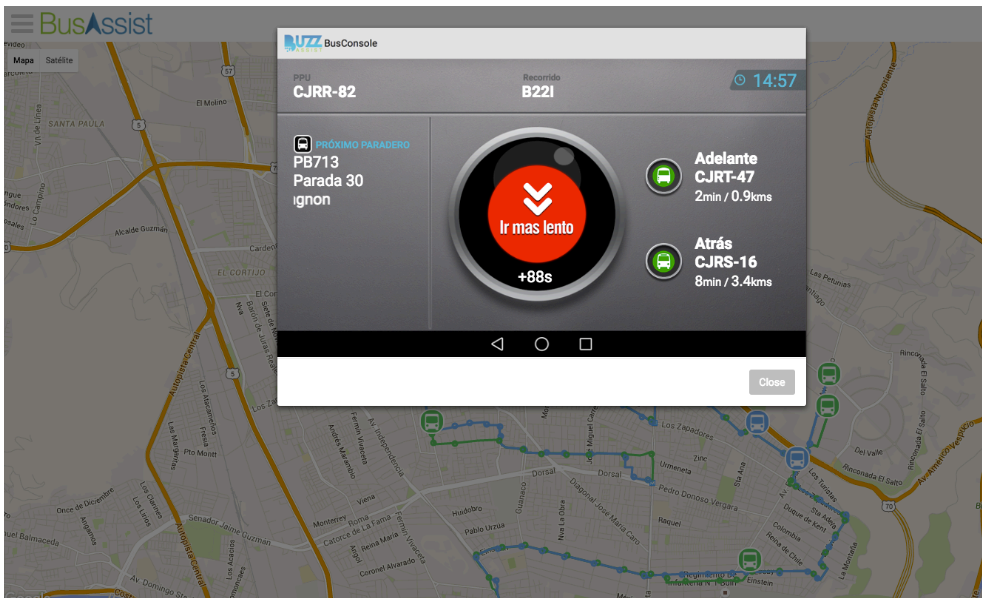
Stopping bus bunching!

- Avoiding bus bunching with schedules or with a state-of-art headway control algorithm





BusAssist

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Driver Assistance

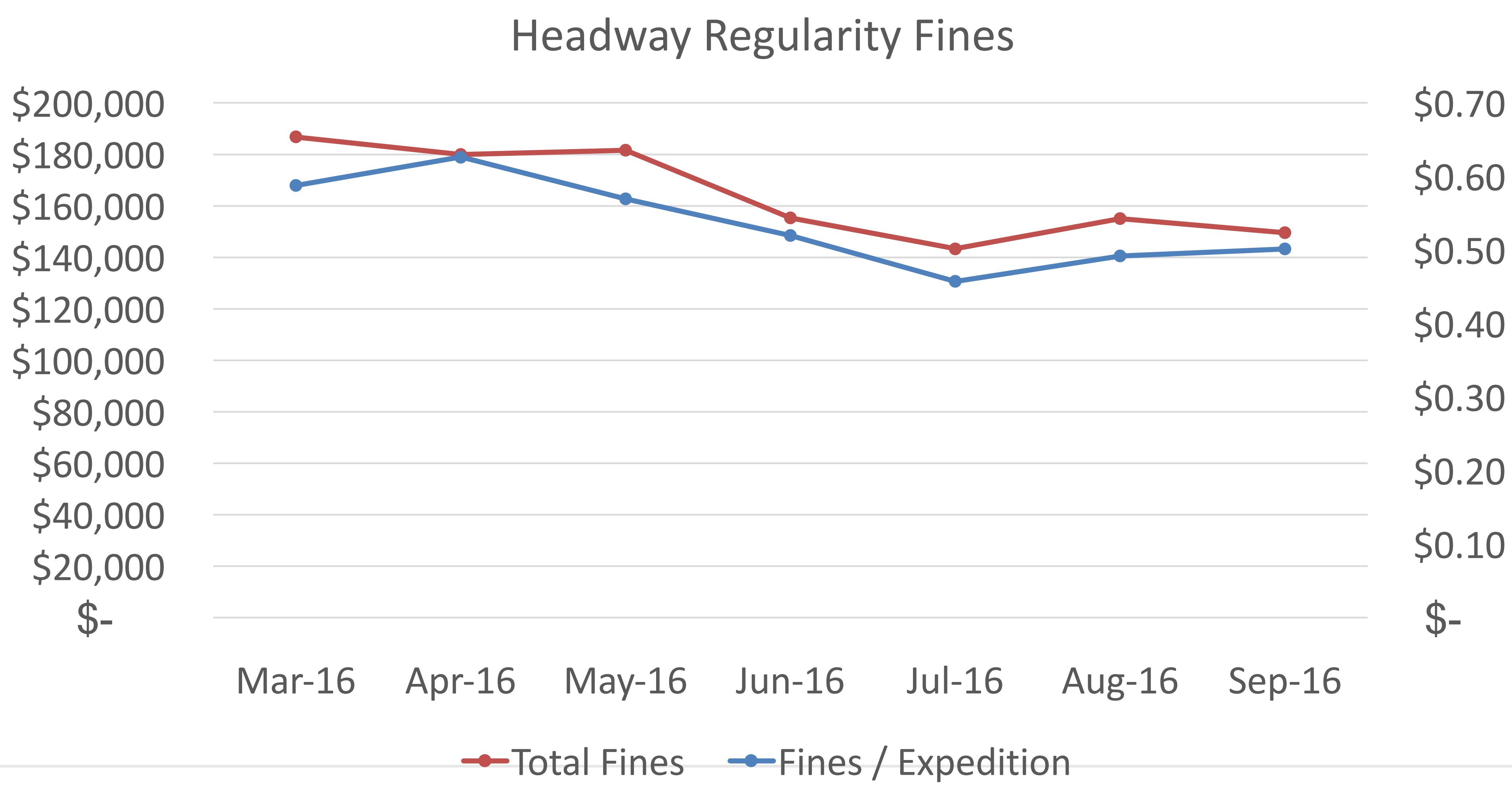
- Drivers receive through an industrial tablet, real-time updates, messages from the control center, and automatized suggestion to increase headway regularity.
- Drivers can also modify expedition parameters, such as the commercial status of the expedition and the line assigned to the bus.
- Industrial tablet is a ruggedized device with Android OS. It has embedded a GPS receiver and GSM communication module, therefore it is flexible enough to adapt to different needs.

Ok **Hold** **Go faster** **Slow down**

Redbus Project

- All 59 services available with the headway dispatching module
- B22 / B14 lines with 25 industrial tablets installed in buses

Results Project Redbus

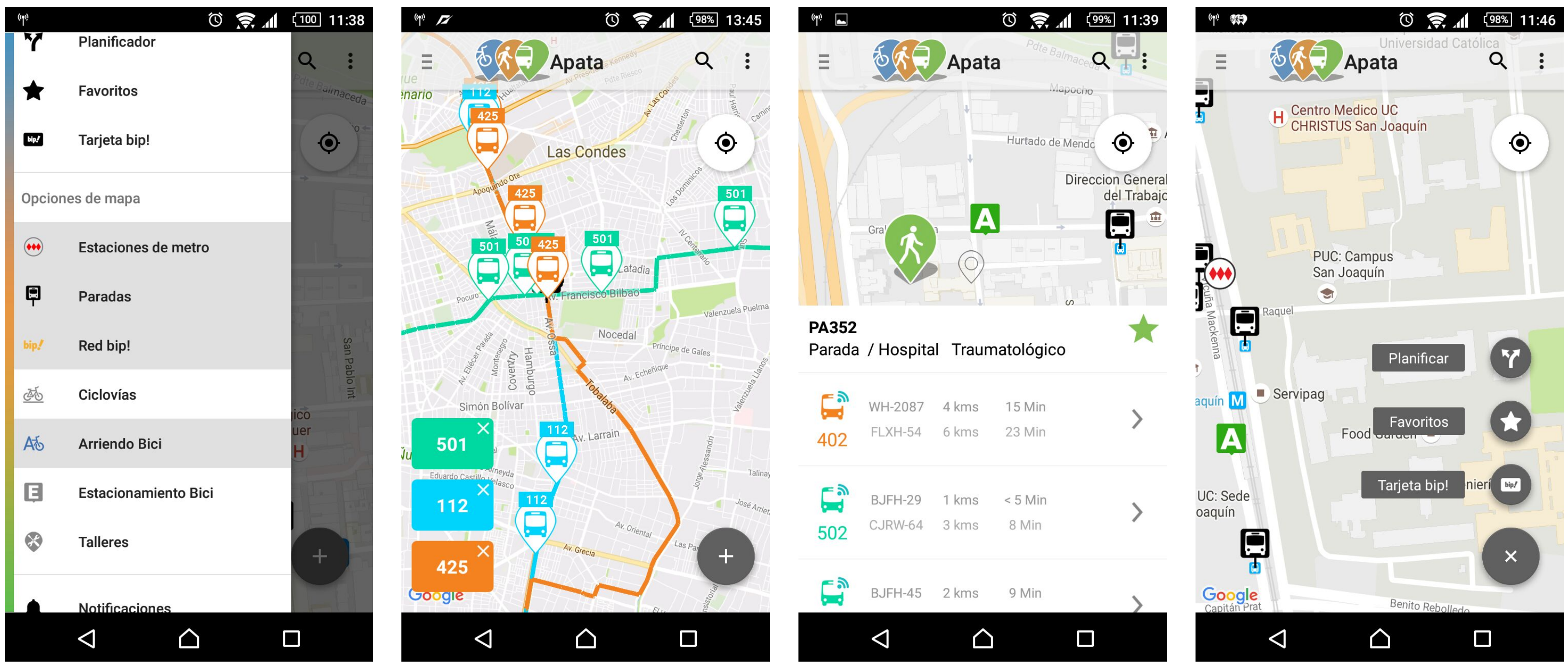


BusAssist TransitUC

Apata: Sustainable mobility App for transit + bike users

- Real-time updates & notifications of bus arrival times, bus location and bus loads
- Multimodal route planner
- Users can evaluate the quality of service

apata



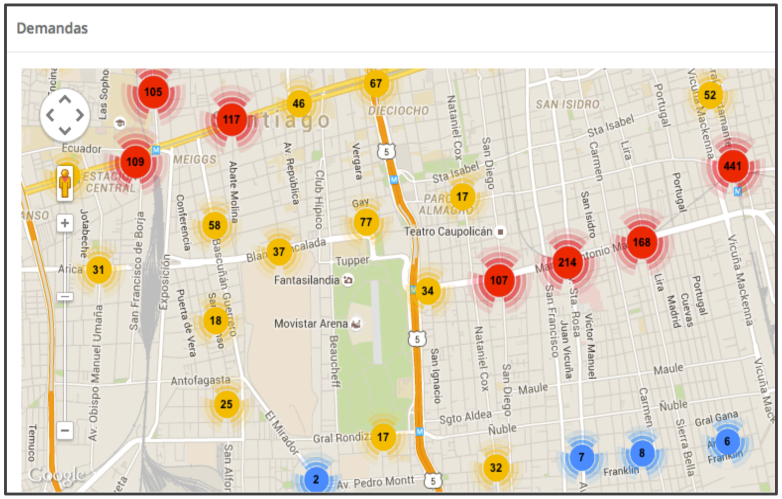
BusAssist

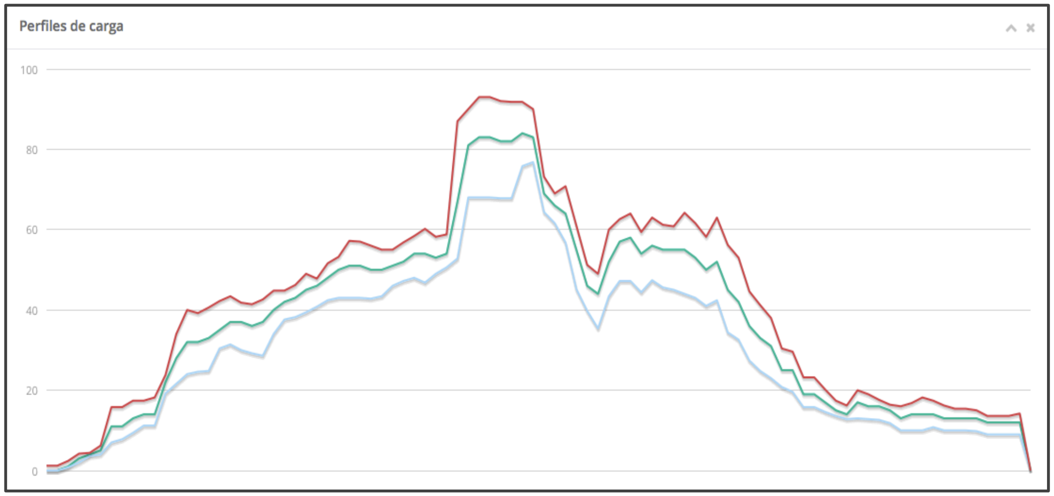
TransitUC

Demand Analysis

We have integrated BusAssist to an electronic fare collection system to estimate the demand of every line and stop:

- How many users board and pay, alight and evade at each stop at any period of the day
- Load profiles
- Give suggestions to monitor and supervise fare evasion





New Challenges … and Opportunities

- More companies around the globe are interested on improving their LOS using our solutions
- How to improve the perception of drivers?
- How to communicate with the driver? Image or voice?
- How to present the information in the monitor?
- Gamification to improve compliance?
  - Ongoing research project FONDECYT Engineering and Design.

Avoiding Bus Bunching: From Theory to Practice

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